THE IMPACT OF MEMORY DEVELOPMENT ON ADOLESCENT EMERGENT READING: INSIGHTS FROM COTE D'IVOIRE

by

Joelle Hannon

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Joelle Hannon

Approved: ____

Kaja Jasińska, Ph.D.
Professor in charge of thesis on behalf of the Advisory Committee

Approved: ____

Robin Andreasen, Ph.D.
Chair of the Department of Linguistics and Cognitive Science

Approved: ____

Debra Hess Norris
Interim Dean of the College of Arts and Sciences

Approved: ____

Louis F. Rossi, Ph.D.
Vice Provost for Graduate and Professional Education and
Dean of the Graduate College

I certify that I have read this dissertation and that in my opinion it meets the academic and professional standard required by the University as a dissertation for the degree of Doctor of Philosophy.

Signed: ____

Kaja Jasińska, Ph.D.
Professor in charge of dissertation

I certify that I have read this dissertation and that in my opinion it meets the academic and professional standard required by the University as a dissertation for the degree of Doctor of Philosophy.

Signed: ____

F. Sayako Earle, Ph.D.
Member dissertation committee

I certify that I have read this dissertation and that in my opinion it meets the academic and professional standard required by the University as a dissertation for the degree of Doctor of Philosophy.

Signed: ____

Roberta Michnick Golinkoff, Ph.D.
Member dissertation committee

I certify that I have read this dissertation and that in my opinion it meets the academic and professional standard required by the University as a dissertation for the degree of Doctor of Philosophy.

Signed: ____

Jennifer Legault Wittmeyer, Ph.D.
Member dissertation committee

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ABSTRACT

Relative to other skills, learning to read requires time and consistent instructional support to master. Reading is a complex skill that relies on multiple cognitive and linguistic abilities including the cognitive ability that underlies all learning, memory. The landscape of memory changes throughout childhood; specifically, procedural learning (which supports sequence and pattern learning) reaches maturity near age 10, while declarative learning (which supports the arbitrary mapping of form and meaning) continues to develop into adulthood. Most reading research takes place in high-income countries where children typically begin learning to read in early childhood, when procedural learning plays a relatively larger role in skill learning. This research, however, does not reflect the experience of many children around the world who learn to read later in childhood or in adolescence when procedural learning is adult-like and the role of declarative learning for skill learning, particularly language related skills, increases. This dissertation presents three studies of procedural and declarative learning's contribution to reading among adolescents in rural Côte d'Ivoire. The first study demonstrates that procedural learning's contribution to emergent reading is through its support of phonological awareness, and this is true for children ages 8-15. The second study evaluated the cultural validity of two measures of declarative learning among children in rural Côte d'Ivoire. This study found that the most reliable measures of declarative learning are those which are based on behaviors children naturally use in their daily life. The final study examined the potential competition between procedural and declarative learning among emergent readers aged 10-16. This study found that declarative learning interferes with the development of early reading skills. Overall, these studies suggest that procedural learning is important for early reading and, among adolescent emergent readers, declarative learning competes with the role of procedural learning

Chapter 1

TESTING THE DECLARATIVE/PROCEDURAL MODEL THROUGH ADOLESCENT EMERGENT READING

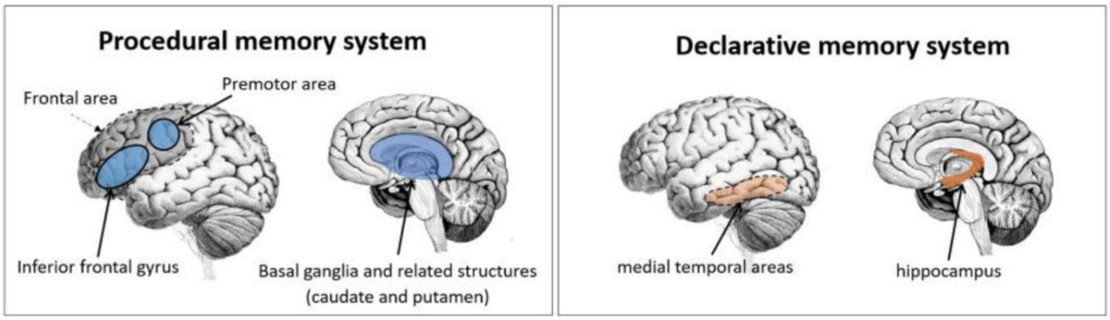
1.1 The Declarative/Procedural Model

Though memory and learning are often used as interchangeable terms, learning describes the encoding of new information, while memory describes the type of information which is stored and the mechanisms for storing and recalling that information. Memory is the nucleus of learning and a multifaceted cognitive ability, different aspects of which support different types of learning (Squire, 1992). The Declarative Procedural Model of language (DPM; Ullman, 2001; Ullman, 2005), suggests that two systems of long-term memory support different aspects of language. The procedural system supports the discovery of patterns and the ability to implicitly learn sequences, including phonological patterns, and employ these learned sequences with automaticity (Ullman, 2013). The declarative learning system supports the mapping of meanings to symbols and the ability to explicitly recognize and recall information, including lexical information (Milner et al., 1968; Ullman, 2013; Squire 1992; Squire & Zola, 1998; Squire et al., 2004; Squire & Dede, 2015).

Procedural learning is associated with rule-governed behaviors and is supported by the basal ganglia, cerebellar, and some frontal brain regions, including the premotor cortex and the inferior frontal gyrus (see Figure 1.1; Suzuki et al., 2022; Longworth et al., 2005; Lum, et al., 2012; Ullman, 2015; Milner et al., 1968; Ullman, 2013; Squire 1992; Squire & Zola, 1998; Squire et al., 2004; Squire & Dede, 2015). This memory is implicit (the individual might not be able to explain how they know what they know) and “non-recollective,” meaning that an individual may access their procedural learning for a pattern with no associated details about when they learned the pattern or even the ability to explicitly describe what the pattern is (Cohen, Poldrack, & Eichenbaum, 1997). Additionally, learning performed by the procedural system is more gradual, requiring multiple exposures and time for the pattern to be extracted and automatized (Ullman, 2004; Hedenius et al., 2012) by the basal ganglia (Ullman, 2004; Ullman 2015; Mochizuki-Kawai, 2008; Knowlton, Mangels, & Squire, 1996). This memory is implicit and "non-recollective" meaning that an individual may access their procedural learning for a pattern with no associated details about when they learned the pattern or even explicitly describe what the pattern is (Cohen, Poldrack, & Eichenbaum,1997). The procedural learning system is proposed to be responsible for those aspects of language that involve the patterns and sequences within language (Ullman, 2004; Ullman et al., 1997; Ullman & Lovelett, 2018).

Declarative learning is supported by hippocampal, temporal parietal, medial temporal, and some prefrontal brain regions, and is associated with the recollection of events and facts (see Figure 1.1; Suzuki et al., 2022; Lum, Conti-Ramsden, Page, & Ullman, 2012; Squire, Stark, Craig & Clark, 2004; Takashima et al., 2006; Ullman, 2004; Ullman, 2015; Ullman et al., 1997). Information stored in declarative learning can be either explicit (meaning that an individual may be able to explain metacognitively what that information is and how they know it) or implicit (meaning that an individual may be able to recognize familiar information without remembering how they know it); however, in either case, the information is generally understood to be rapidly encoded (Henke, 2010; Ullman & Pullman, 2015). The declarative learning system is proposed to be responsible for those aspects of language that involve the arbitrary mapping of meanings to forms (Ullman, 2004; Ullman et al., 1997; Ullman & Lovelett, 2018).

Figure 1.1: Brain regions related to the procedural and declarative memory systems. From "An fMRI validation study of the word-monitoring task as a measure of implicit knowledge: Exploring the role of explicit and implicit aptitudes in behavioral and neural processing," by Y. Suzuki et al., 2022, Studies in Second Language Acquisition, 45(1), CC BY.



While the behavioral definitions of procedural and declarative learning as implicit and explicit respectively are imperfect, early work identifying the dissociability of the declarative and procedural systems came from individuals with brain damage to medial temporal or hippocampal regions who struggled to learn new explicit information and recall facts and events, while still remaining capable of learning *implicit* sequences (Squire 1992; Squire & Zola, 1998; Squire et al., 2004; Squire & Dede, 2015). The most famous of these cases, H.M., was not able to form new explicit memories (e.g., people he met), but he was able to form new implicit memories (e.g., improve performance on a card sorting task; Milner et al., 1968; Squire, 2009; Mishkin & Appenzeller, 1987). Similar observations of amnesiacs with either temporal region lesions or Alcoholic Korsakoff Syndrome (anterograde amnesia caused by heavy alcohol use) demonstrated that intact procedural learning (i.e. able to recognize words from visual word fragment patterns) could persist even when declarative learning was impaired (i.e., were not able to recognize words they had seen previously in a passage; Mishkin & Appenzeller, 1987; Oscar- Berman & Evert, 1997; Roediger, 1990; Warrington & Weiskrantz, 1970). Based on these, and other accounts, it is inferred that the declarative and procedural learning systems provide two dissociable paths to learning.

The DPM also posits a "see-saw effect," that is, as declarative learning matures, declarative support of skill learning increases in importance and may compensate for, or compete with, procedurally supported skill learning (Ullman 2001; Ullman 2006; Poldrack et al., 2001). While early skill learning is supported primarily by procedural learning, both procedural and declarative learning systems are engaged in early skill learning as learners age (Foerde et al., 2006; Lum et al., 2010). By comparison, declarative learning and its supported learning skills are largely immature in younger children. For example, one study found that children ages 8 and 12, who performed similarly on a procedural task of identifying degraded pictures, demonstrated stark age-related differences when asked to recall as many items as possible that they had seen in the degraded picture task (DiGuilio et al., 1994). That is, 8- and 12-year-old children performed equally well on the procedural learning component of the task, but 12-year-old children performed significantly better than 8-year-olds on the declarative learning component of the same task. Further, Finn and others (2016) found that while the children aged 10 did not differ from adults in a battery of implicit sequence learning tasks such as probabilistic classification and artificial grammar learning, differences emerged between 10-year-olds and adults when they were asked to recall words from a list after a delay (supported by declarative learning), suggesting that the increasing importance of declarative supported learning might be in part due to the increasing development of the declarative learning system as an individual ages (Nicolson & Fawcett, 2007).

1.1.1 Memory and Language

The DPM posits that the declarative and procedural learning systems support different abilities in language, including language learning (Ullman et al., 1997). According to the DPM, procedural learning supports the discovery of relationships and structures with language (i.e., phonological structure and grammar) through the automatic and implicit extraction of sequences and patterns which is characteristic of procedural learning (Hedenius et al., 2012; Ullman, 2004; Ullman et al., 1997; Ullman &

Lovelett, 2018).

The DPM's claim for the role of procedural learning in language is founded in many accounts that link phonological and morphosyntactic processing to the procedural system. For example, phonological patterns, or phonotactics (e.g., rules related to the permissible combinations of sounds and syllables in a language), emerge from repeated exposure across many words and the ability to predict what sounds should, and can, co-occur has been linked to procedural learning (Cohen, Poldrack, & Eichenbaum, 1997; Conway & Pisoni, 2008; Goschke, Friederici, Kotz, & Van Kampen, 2001; Warker, 2013). In adults, a measure of implicit pattern learning was linked to the ability to understand degraded recordings of speech (Conway et al., 2007). The basal ganglia, associated with procedural learning, is also essential for phonological category learning (Maddox & Chanderasekaran, 2014). The relation between procedural learning and phonological processing in adults is well supported. Conway and Pisoni (2008) found that the general pattern learning required to remember a rule-governed spatial or color pattern was closely associated with a listener's ability to recognize phonological patterns in degraded speech and fill in the missing information. Further, procedural learning skills were associated with better novel sound category learning in adults, specifically when participants were trained on novel sound category learning over two days (Quam et al., 2018). Additionally, contributions of procedural learning for non-native phonological category learning is thought to account for children's greater success in acquiring the phonology of the second language compared to adults; children learn to adjust their native phonological categories through a reliance on procedural learning while adults rely on less effective declarative strategies (Ullman, 2001; Maddox & Chandrasekaran, 2014).

Procedural learning supports implicit learning abilities (i.e., learning which is below conscious awareness; Seger, 1994). Skills which are often associated with procedural learning include statistical learning, the implicit ability to observe the probability of co-occurrent stimuli and leverage these probabilities for learning (Arciuli & Simpson, 2012; Qi et al., 2019; Torkildsen et al., 2019). Sequence learning is similar to statistical learning in that it refers to implicitly acquired knowledge of patterns over time and frequent exposure, but sequence learning has the added constraint of these patterns occurring in a serial-order chain (Toth-Faber et al., 2021). A longitudinal study of children through their first year of reading instruction found that in very earliest stages of reading acquisition children depend on short-term sequence learning abilities to support decoding as they must keep each successive relation between phoneme-to-grapheme in mind while building towards the completed word (Nithart et al., 2011). Further this short-term memory for sequences contributes most to early reading but is replaced in importance by the knowledge of phonology stored in long-term memory as reading skills mature and children become able to recognize words they have seen before (Nithart et al., 2011).

Both statistical and sequence learning, however, are not exclusively supported by procedural learning related systems. Declarative learning is most often associated with explicit learning abilities (i.e., learning which can be effortful and often involves a conscious awareness; DeKeyser, 2008) but declarative learning can also support implicit and statistical learning abilities (Batterink et al., 2019). The involvement of procedural learning in either a statistical learning or a sequence learning task appears to be related to learning which is dependent on a participant's ability to make predictions about the stimuli (Erickson & Thiessen, 2015; Karuza et al., 2013; Ceballos et al., 2020). For example, in a study of statistical learning of three syllable non-words containing high transitional probabilities between the consonants, participants were exposed to these non-words in a training phase and were later asked to recognize non-words they had heard before. This exposure and testing phase were repeated three times. Under this paradigm, participants could use their previous experience with the initial syllable of a word to predict the subsequent syllables and successfully identify words which they had heard before (Karuza et al., 2013). Further, fMRI observations during the performance of this task revealed a relation between learning and activity in regions associated with procedural learning (i.e., the inferior frontal gyrus and basal ganglia; Karuza et al., 2013) suggesting that the task does indeed engage the procedural learning system.

Among sequence learning tasks, the serial reaction time task has also been shown to engage procedurally-related brain regions (Earle et al., 2021; Janacsek et al., 2020.). Initially designed by Nissen and Bullemer (1987), the task presents an image appearing at one of four potential positions on a spatial array and asks participants to press buttons corresponding to this position as quickly as possible. The image can appear in either a random or sequential order and the difference in reaction time between these two orders provides an indication of an individual's ability to generate and refine predictions of patterns over time (Nissen & Bullemer, 1987). The ability to generate and refine predictions is demonstrated as a child improves (becomes faster) during the sequenced trials, over time and with many repetitions of the sequence. This task, too, encourages learning through positive feedback from correct predictions as a participant learns to anticipate where the next image in the sequence will appear and can move more quickly if they can accurately make these predictions (Erickson & Thiessen, 2015) suggesting that the procedural learning system supports the task.

For declarative learning, the DPM posits that it supports semantic/lexical processing (Pinker & Ullman, 2002; Ullman et al., 1997). Previous research under this framework found that individuals with damage to brain regions associated with declarative learning had greater difficulty producing irregular verbs which, according to the authors, must be stored as whole past-tense forms in the lexicon as opposed to produced through morphosyntactic processing as regular past-tense verbs (Ullman et al., 1997). Further evidence also supports the role of declarative learning in lexical/semantic processing as adults depended more on explicit learning. Adult performance in an artificial word learning task was faster than that of children, but degraded more than children's over time (Smalle et al., 2014). Importantly, this study also indicates that children, whose declarative learning system is relatively immature, will rely on procedural learning to notice patterns in phonological sequences or syllabic structures within words rather than encoding the whole word (Smalle et al., 2014; Smalle et al., 2015). The DPM suggests that learning supported by the declarative system increases in importance for language- related learning as individuals age, though others do suggest that immature cognitive abilities such as attention and working memory also contribute to the early reliance on implicit/procedural learning (Smalle et al., 2017).

Further evidence to support the increasing role of declarative learning-supported learning for language learning throughout development comes from research into second language learning. Adults in the early stages of learning a second language for the first time will often rely on explicit learning strategies through which they rote memorize chunks of language (i.e., sentences or phrases) which match the correct grammar of their second language, rather than producing sentences through morphosyntax (DeKeyser, 1994; Roehr, K. 2004). One study found that declarative learning supported early acquisition of an artificial second language syntax but that, as proficiency increased, procedural learning began to support second language syntax learning (Morgan-Short et al., 2014). In another study using a productive grammar task, multilingual individuals with aphasia affecting the basal ganglia omitted more grammatical function words in their first language than in their second language (Fabbro & Paradis, 1995). Potentially the initial declarative support of second language can explain why adult second language learners often struggle, specifically with the structural aspects of their second language.

As a second language learner becomes more skilled, however, they may rely differently on declarative learning. That is, less skilled second language relies on explicit recollection of second language semantic forms, then, as the learner becomes more skilled, the patterns within these forms slowly become proceduralized allowing the learner to use the morphosyntactic rules of the second language (Anderson, 1987; Ullman & Lovelett, 2018; Willingham, Nissen, & Bullemer, 1989). A demonstration of this proceduralization was observed in adults learning an artificial language whose neural responses to grammatical structures at earlier levels of proficiency evoked neural responses related to semantic processing but became increasingly ‘native-like’ as they mastered the language (Morgan-Short et al., 2012). Given the above, the proposed increasing importance of declarative learning among older learners is potentially complex and currently unclear.

1.1.2 The Role of Memory in Typical Reading

Multiple cognitive and linguistic abilities predict success in learning to read, including domain general cognitive functions which help early readers focus and apply the rules of written language to the text they see (Mulder et al., 2017; Gooch et al., 2016). Language skills are unsurprisingly vital for the earliest stage of reading, emergent reading, which relies on knowledge of vocabulary and the ability to decode written words (Jasińska & Petitto, 2018; Goswami, 2008; Hulme et al., 2002; Rack et al.,1993; Pugh et al., 2001; Tannenbaum et al., 2006; Stahl & Murray, 1994; Wagner & Torgesen, 1987). Indeed, according to the 'simple view of reading' both decoding and language comprehension skills work in tandem towards the development of reading comprehension (Hoover & Gough, 1990).

Early reading abilities rely on a reader's knowledge of language. When learning to read in an alphabetic system, a reader typically first learns to decode; that is, learns to associate graphemes (e.g. letter, or letter combination, 'th') with phonemes ('θ'or 'ð'). Particularly, on the metalinguistic knowledge of phonological awareness, an aspect of phonological processing which includes the understanding of the patterns and rules for sound combinations within a language (Castles & Coltheart, 2004; Hogan, Catts, & Little, 2005; Wagner & Torgesen, 1987). Phonological awareness is, in part, an individual's ability to recognize that the sounds of their language are isolatable elements which can be remixed to form new words (Lum et al., 2013; Goswami, 2008). Phonological awareness skills include abilities such as blending (i.e., hearing the separated individual phonemes of a word in sequence and then reciting the completed word), segmentation (i.e., breaking a word into its individual component phonemes), and elision (i.e., removing part of a real word to make a new real word, e.g., 'popcorn' without 'pop' makes 'corn'). The phonological skills which are important for reading, have a reciprocal relation to reading such that as reading develops phonological awareness skills improve and vice versa (Castles & Coltheart, 2004; Hogan, Catts, & Little, 2005; Wagner & Torgesen, 1987). For example, adults who were learning to read for the first time in their second language demonstrated improvement in their second language phonological processing as their decoding skills improved (Tarone, 2010). Beyond decoding, a reader must also learn to associate visual representations of letters and words with mental representation of phonological and semantic information; thus, vocabulary knowledge is also a key component of skilled decoding (Duff et al., 2015). This mapping between phonology, orthography, and semantics (Harm & Seidenberg, 2001) is the core of skilled reading and allows the reader to decode words with automaticity and quickly recognize exception words (i.e., words that don't sound like they look; Windfuhr & Snowling, 2001). Emergent readers rely more heavily on phonological information when first learning to read, but as emergent readers become more skilled, this reliance on orthography-to- phonology-to-semantics shifts towards a greater reliance on vocabulary knowledge and to a more direct orthography-semantic mapping (Cain & Oakhill, 2014, Harm & Seidenberg, 2004). As readers' semantic memory develops, they accumulate experiences and world knowledge, allowing for greater reliance on abstract information and less on directly perceptual information which in turn supports the development of new skills (DiGuilio et al., 1994; Ofen & Shing, 2013). For learners entering adolescence, procedural learning, which aids automaticity and supports abilities closely linked to early reading skills (e.g. phonological awareness), is more fully developed compared to younger readers (Finn et al., 2016). As declarative learning develops, adolescent readers will also have increasing abilities to recall and explicitly employ the rules of written language.

1.2 The DPM and Emergent Reading

When learning to read, a learner must draw on multiple cognitive and linguistic abilities, including procedural and declarative memory. If, as the DPM posits, procedural learning is the system supporting phonological pattern knowledge and the automaticity of learned skills, then it follows that procedural learning must be crucial to early reading acquisition, as the earliest stages of emergent reading (i.e., when nascent reading skills are beginning to develop but the learner cannot yet read) depend on the ability to extract information regarding the segmental nature of language from spoken language and apply this segmental knowledge to the phoneme-to- grapheme mappings of written alphabetic language (Castles & Coltheart, 2004; Hogan, Catts, & Little, 2005; Wagner & Torgesen, 1987). Indeed, the DPM predicts that the shift in support for skill learning between memory systems indicates skills typically supported by procedural learning in early life may instead be supported by declarative learning as the individual ages. These declarative-supported skills are functionally from skills acquired through procedurally- supported learning (Ullman, 2004). For children learning to read on this timeline, phonological skills (supported by procedural learning) are a strong predictor of early reading, while later and more skilled reading vocabulary (supported by declarative learning) becomes an important predictor (Tannenbaum et al., 2006). These predictions align well with the reading development trajectories observed among children who start formally learning to read upon entry into the school system, typically around 5-6 years of age. The developmental timeline for declarative and procedural learning raises new questions about the relative contributions of each system to emergent literacy development beyond early primary school.

Within typical developing groups, younger children rely more heavily on the pattern learning supported by procedural learning (Mayor-Dubois, Zesiger, Van der Linden, & Roulet- Perez, 2016). For reading, children, aged 7, have been shown to learn the sequential rules of orthography (i.e., how a subsequent grapheme can change the sound of the previous grapheme) through exposure to many similar examples (Apfelbaum et al., 2013). As learning sequential patterns across many variable exposures is characteristic of procedural learning, this suggests that procedural learning plays a role in early emergent reading, specifically the sound to grapheme mappings which underlie decoding abilities. Further, both procedural learning and reading skills share patterns of neural activation across the same brain networks, suggesting that these shared neural networks indicate that both skills draw on related processes (Hung et al., 2019). For example, motor learning and orthographic learning are both supported by parts of the inferior frontal gyrus and by the insula (Hung et al., 2019). Procedural learning, therefore, likely supports early reading development as a reader must learn to decode words with automaticity by recognizing patterns across both phonology and orthography (Nicolson & Fawcett, 2007).

Declarative learning system supports vocabulary growth, which is also key to the development of reading, and increases in importance over time (Lum, Conti- Ramsden, Page, & Ullman, 2012; Ulman & Lovelett, 2016; Earle et al., 2020). Declarative learning also supports the ability to recognize whole word forms which the skilled reader has seen before (Lum, Conti- Ramsden, Page, & Ullman, 2012; Ulman & Lovelett, 2016; Earle et al., 2020). Potentially, as the declarative system develops, an emergent reader may rely more on this whole word recognition rather than decoding. Declarative related abilities such as recall continue to improve as children age into adolescence and young adulthood (DiGiulio et al., 1994; Lum, Kidd, Davis & Conti- Ramsden, 2010; Ofen & Shing, 2013). Adolescent children begin to use more declarative- supported learning in their skill acquisition (Mayor-Dubois et al., 2016) It is, therefore, possible that learning to read also becomes more reliant on declarative learning as the individual ages. Indeed, one study found that in older (and more skilled) readers, aged 7-11, declarative learning was correlated with word and non-word reading abilities while procedural learning was not (West et al., 2019), suggesting that declarative learning increases in importance either as children age or become more skilled readers. Additionally, for children 7-13 years old who were learning to read in their second language, declarative learning was related to reading skill (Sengottuvel et al., 2020) indicating that when linguistic knowledge more generally is supported by declarative learning, as second language learned later in life is proposed to be, then it is declarative learning also supports the acquisition of language adjacent skills (e.g., reading) to a greater extent than procedural learning.

While vocabulary learning is available beyond proposed sensitive periods for language learning, phonological skills may become more difficult to acquire with age (Kuhl, 2010; Birdsong, 2018). Despite the potential decrease in phonological learning with age, however, newly literate children and adults demonstrate similar phonological awareness skills and improvement of these skills with emergent reading (Young-Scholten, 2015). Some evidence from a literacy intervention for adult emergent readers in Turkey suggest that phonological awareness, not vocabulary or word recognition, remains the most important factor in the early reading development (Durguno-lu & Öney, 2002). Others also point to the consistent importance of phonological skills supporting decoding among emergent readers regardless of age (Kitz, 1988; Kruidenier, 2002; Fracasso et al., 2016).

It is important to note that, while phonological awareness is typically supported by procedural learning among children, among older learners this is not necessarily the case. Indeed, phonological processing skills, including phonological awareness, were predicted by declarative and not procedural learning scores in skilled adult readers (Arthur et al., 2021). Arthur et al. (2021) found that adult performance in a non-word repetition task was predicted by immediate declarative learning abilities, which may be due to the greater lexical knowledge of adults providing a scaffolding for the sound patterns of novel but phonotactically plausible words. Additionally, Arthur et al., (2021) also found that phonological awareness skills, such as blending and elision, were predictive of declarative learning after a delay, indicating that long- term storage of phonological information likely contributes to online auditory task demands such as attention and working memory. Potentially, the phonological skills vital for emergent reading can be supported through the explicit strategies of the declarative system such as accessing the lexical and phonological storage in long-term memory. Likewise, if declarative learning supports the ability to explicitly recall information, including explicit rules for mapping sounds to text and lexical knowledge, then it too must play a role in early reading as both explicit sound-to-grapheme mappings (Earle et al., 2021) and vocabulary knowledge also vital for emergent alphabetic reading (Duff et al., 2015).

The importance of phonological over word-level skills among adult readers points towards a model of emergent reading where early skills are best supported through phonological skills that are in turn (typically) supported by procedural learning. Yet, among adults, phonological awareness is not necessarily acquired or supported through procedural learning. Declarative learning complicates the question of older emergent reading as, not only can it support whole word recognition, it can also support phonological awareness and decoding. It is unclear, therefore, what the role of procedural learning and decoding would be for typically developing, older, emergent readers in the face of this declarative competition. The DPM points to a possibility for growing reliance on explicit/declarative learning, including skills which might have been supported by implicit/procedural earlier in life. Potentially declarative support offers an alternative for the skills supporting emergent reading which might have been supported by implicit/procedural learning had declarative learning been less mature. Do the procedural and declarative learning systems support literacy in the same manner for all children, both younger and older emergent readers?

Table 1.1: Summary of highlighted evidence for the role of procedural and declarative learning in typical reading.

Study	Population	Methods	Results	Inference
Apfelbaum et al., 2013	224 school children in the US, age 7.	Learning grapheme-phoneme-correspondence regularities for vowels.	Better learning after multiple exposures to similar examples.	Procedural learning supports grapheme-phoneme mapping in children.
West et al., 2019	101 school children in the UK, 52 spoke English as a second language, ages 7-8.	Measured verbal and non-verbal declarative learning, word reading, and nonword reading.	Verbal declarative learning was moderately correlated with reading.	Declarative learning supports word reading among skilled second language speakers and first language speakers.

Sengottuvel et al., 2020	44 school children in India, all spoke English as a second language with an early age of exposure.	Measured non-verbal declarative learning, word reading, and spelling.	Better readers demonstrated better declarative learning after a delay.	Declarative consolidation supported better reading among second language users.
Arthur et al., 2021	79 adults, all spoke English as a first language.	Measured non-verbal declarative learning, procedural learning, and phonological processing.	Declarative learning supported phonological processing.	Declarative learning can support phonological skills among adults.

1.2.1 Compensation and competition

While both declarative and procedural learning likely play a role in emergent reading, the skills developed later in life, including emergent reading, may be differentially supported by procedural and declarative learning. Importantly, while the above studies demonstrate that procedural learning supports early decoding and declarative learning supports later, more skilled decoding, no study, as of yet, can separate age from skill such that older children in the above (and indeed the majority of reading research) are always more skilled readers. If the DPM is correct in its assertion of a "'see-saw effect" between these memory systems such that learning through one system may suppress learning through the other system (Ullman 2001; Ullman 2006), then learning in older but less skilled emergent readers may be differentially supported by the declarative and procedural learning systems. Specifically, as declarative learning matures, it is associated with an increasing role in learning in older children in tasks such as probabilistic classification learning, which was supported by procedural learning in younger children (Mayor- Dubois et al., 2016). The DPM points specifically to the onset of puberty leading to changes in the neurochemistry which benefit regions of the brain associated with declarative learning (Ullman, 2004). This assertion is supported by observations that increased activation in declarative-related neurological regions is associated with depressed activation in procedural- related regions (Poldrack et al., 2001). Potentially, as an emergent reader approaches puberty, more mature declarative learning becomes more important in supporting emergent reading regardless of the skill level of the reader. Still, procedural learning is linked to reading fluently with automaticity as children who struggle with both the rapid processing and decoding of written language often also demonstrate poor procedural learning (Nicolson & Fawcett, 2007; Nicolson & Fawcett, 2007; Nicolson & Fawcett, 2019). In procedurally-related regions, increased neural activation for sequential patterns as compared to random patterns was associated with better decoding ability in a reading task (Hung et al., 2018). Additionally, phonological awareness is essential in making associations between phonemes and graphemes which is fundamental for decoding in the earliest stages of reading development (Goswami, 2008) and it is supported by brain regions also associated with procedural learning, such as parts of the basal ganglia (Tettamanti et al., 2005).

The potential compensation of declarative learning for typically procedurally-supported skills has largely been studied in groups who are thought to have some procedural deficit, not in typically developing individuals. Developmental dyslexia (DD) is a neurobiological disorder characterized by a difficulty attaining literacy not otherwise caused by secondary factors such as IQ. A potential cause for DD is poorer phonological processing due to reduced procedural learning capacity resulting in weaker phonological representations (Lum, Ullman, & Conti- Ramsden, 2013; Nicolson & Fawcett, 2007; Snowling & Griffiths, 2004). Some speculate that, among individuals with dyslexia who successfully learn to read, an intact declarative learning may compensate for the impaired procedural system (Lum et al., 2013; Ullman & Pullman, 2015). Declarative learning compensation for a procedural learning impairment increases reliance on semantics (including using the context of surrounding words), memorization of the whole word, and explicit recollection of rules for decoding unfamiliar words (Lum et al., 2013; Ullman & Pullman, 2015). This compensation may be characterized as a relative strength in declarative learning;

indeed, individuals with DD have demonstrated relatively better performance than neurotypical control individuals in declarative learning tasks (i.e., involving the recollection of items seen only once before; Hedenius et al., 2013). Interestingly, the individuals with DD who demonstrated the strongest performance on declarative learning tasks were also the strongest readers, providing compelling support that declarative learning can support alternate routes into skilled literacy by compensating for an impaired or immature procedural learning (Hedenius et al., 2013; Ullman & Pullman, 2015).

For individuals with DD, declarative learning offers an alternate route to reading through rote memorization and associative memory supported by this system, however, this alternate route to reading might mean that the individuals who utilize it do not develop the automatic decoding skills of a typical reader. Indeed, difficulties with decoding unfamiliar words follow individuals with DD well into adulthood as adults with DD demonstrate slower processing and less accuracy in nonword reading compared to typically developing readers despite being able to comprehend reading at the college level (Oren & Breznitz, 2005). Compared to rote memorization, decoding is a more efficient strategy for emergent reading as it can be used for unfamiliar and familiar words alike. Indeed, younger emergent readers' reliance on phonological awareness seems to suggest that understanding the segmental nature of speech and using that knowledge to learn phoneme-to-grapheme mappings in written language is a reliable path to successful literacy acquisition.

For emergent readers, phonological awareness appears to support developing decoding skills regardless of the age of the learner (Kitz, 1988; Kruidenier, 2002; Fracasso et al., 2016; Durguno-lu & Öney, 2002; Young-Scholten, 2015). Among adults, phonological awareness may also be supported by declarative and not procedural learning (Arthur et al., 2021). Alternatively, learning rules which require the integration of visual and verbal information has been shown to be most successful when it is supported by implicit/procedural learning (Maddox et al., 2006; Quam et al., 2018). Understanding the relative contributions of memory systems as they mature to emergent literacy is hindered by very little research addressing the topic of emergent adolescent literacy. Instead, much of the previous research into adolescent reading has centered on the issues surrounding reading comprehension, a skill which becomes relevant only after a learner has progressed past the emergent stages of reading development and become a more skilled reader (Goldman, 2012; Lee & Spratley, 2010; van Gelderen et al., 2007; Vacca, 1998). Research of adolescent comprehension often points to vocabulary knowledge as a predictor of skilled reading (Duncan et al., 2016; Clemens et al., 2017; Suggate et al., 2018; Elleman et al., 2009; Oslund et al., 2018). One study found, however, that while vocabulary was the strongest predictor of reading for children around 14 years of age who were skilled in comprehension, for those who struggled with comprehension being able to identify words by sight was the stronger predictor of skilled reading (Oslund et al., 2018), indicating that decoding skills remain vital to reading among children struggling to transition between emergent and skilled reading. Likely, before a reader's skill progresses beyond emergent reading to comprehension they must first master the ability to decode written language at the word level. Some researchers point to age differences in the importance of decoding for comprehension such that younger readers depend more on decoding than older readers (Garcia & Cain, 2014; Gough et al., 1996; van Steensel et al., 2014), however, in this previous work older readers were also skilled readers. Very little work has examined the factors which contribute to reading development among adolescents in their early stages of reading, such as emergent reading. These observations raise a hypothesis: If the skills which support early reading acquisition are best supported by procedural learning then, regardless of age and memory development, procedural learning should support emergent reading skills.

The above hypothesis cannot be evaluated when the lion's share of reading research takes place in contexts where children consistently begin learning to read around age 5. Previous studies have been unable to separate the age of the emergent reader from emergent reading skills. Understanding how emergent reading at puberty age and beyond is impacted by cognitive development is crucial as millions of children around the world may start learning to read well into adolescence (i.e. ages 10-19; World Health Organization, 2014).

1.3 The Study Context

The proposed studies included in this dissertation take place in low-literacy rural regions of Côte d'Ivoire. Côte d'Ivoire has a largely agricultural economy, where 28.2% of the population living on less than $1.90/day, below the international poverty line (World Bank, 2020). Despite efforts to curtail it, child labor remains a serious problem, particularly in rural areas with 31.5% of children ages 5-14 working and 21.5% engaged in hazardous work and therefore either not attending or irregularly attending school (Bureau of International Labor Affairs, 2017). Crucially, despite compulsory school enrollment beginning at age 6 (UNESCO, 2021) many children in rural Côte d'Ivoire begin their schooling as late as age 12 or as young as four years of age (Heugh, 2011; PASEC, 2014), leading to highly variable ages within the same classroom. Many children repeat grades and absenteeism is common. Consequently, less than half of children continue attending beyond a primary school and many who complete primary school are still functionally illiterate, with some remaining at the earliest stages of emergent literacy (Heugh, 2011). Around half of the adult population of Côte d'Ivoire is illiterate (CIA Factbook, 2012; UNICEF, 2013).

The context of Côte d’Ivoire provides the opportunity to examine how children entering adolescence and beyond learn to read. Specifically, whether younger and older emergent readers rely on procedural and declarative learning similarly or dissimilarly when encountering written language for the first time. In classrooms with both younger and older children, students receive the same reading input, albeit at different stages of development. A later start to education may have an adverse impact on their reading achievement, however, the number of contributing factors in a child’s environment make it difficult to parse out the exact role that the home and educational environments contribute to a child’s academic success. Late age at school enrollment may also reflect lower socioeconomic status (SES) and related factors (i.e. child labor, supervising younger siblings, helping parents at work), which are likely to contribute to poorer academic outcomes (Zhang et al., 2020). Crucially, if the child's home literacy environment is poor (i.e., no literate adults in their family, no access to books) then a later age at school enrollment also corresponds to later exposure to literacy; growing up with parents who are illiterate is linked to poorer reading outcomes (Menheere & Hooge, 2010). Many children in Côte d'Ivoire grow up in non-literate households (CIA Factbook, 2012; UNICEF, 2013), therefore, while later age at school start on its own may not be the cause of a child's academic challenges, it is indicative of other contributing factors, particular later exposure to literacy.

Additionally, while schools in Côte d'Ivoire may be either monolingual (i.e., French speaking) or bilingual (i.e., French and a local language), literacy education is entirely devoted to French literacy. Many of the children learning to read for the first time in French do not speak French as a first language and their exposure to French begins when they start school (Ayewa, 2018; Brou-Diallo, 2011). Later school enrollment, therefore, means a later start in learning the language of literacy and might present a disadvantage for children which might contribute both to lower phonological awareness scores as well as to reading scores. While second language proficiency is related to reading comprehension (Droop & Verhoeven, 2003), decoding may not be as reliant on language proficiency (Spencer & Wagner, 2017). However, it is still likely that French phonological awareness is related to French language proficiency.

Issues such as later literacy exposure and learning in a language not spoken at home may go some way in explaining why, in Côte d'Ivoire, previous research has found that older children tend to be poorer readers than younger children in the same grade (Hannon et al., 2020; Whitehead et al., *in press*). The apparent disadvantage of an older age for reading in Côte d'Ivoire highlights the importance of reading research in contexts other than high-income countries (HICs) where older children would be expected to read at a higher level. In particular, it is important to understand how cognitive maturation interacts with emergent reading among older emergent readers.

1.4 Cultural Validity of Declarative Learning Methods in LMICs

In order to address the role of declarative learning in emergent readers in Côte d'Ivoire, however, special care must be given to the measures of declarative learning used. While other long-term memory abilities, such as procedural learning skills, can be measured in relatively culturally neutral ways, measuring declarative learning is difficult in populations with limited experience with technology, test taking procedure, and different world knowledge than might be reflected in the stimuli of existent assessment measures. For most who have grown up in places like the United States or Europe, the experience of sitting quietly and answering test questions is very familiar and something that school children encounter on a regular basis. For many non-literate individuals around the world, this is not the case (Tarone, 2010). Further, experimental designs that use pretend play may not translate well to cultures that have limited interaction between children and adults (Kolling et al, 2015). Finally, many assessments widely used in the US are designed with forced choice and limited feedback for participants, which may lead to participants guessing or failing to understand the task. Given the above, it is therefore vital to determine the cultural validity, or the impact of a participant's socio-cultural expectations on assessment performance (Kūkea Shultz & Englert, 2021; Solano-Flores, 2011), for any measure of declarative learning in a new context.

1.5 Goals

In this dissertation, I will examine the relative contributions of procedural and declarative learning for emergent reading at different ages. Specifically, I will evaluate the relative contributions of procedural and declarative learning to emergent reading in rural Côte d'Ivoire where the age at which a child enters school, and therefore begins learning to read, is highly variable. Children in Côte d'Ivoire may enter school, and therefore begin learning to read, as late as age 12. In order to appropriately address the goal of evaluating the impact of memory development on emergent reading I will need to first establish both: 1) the contributions of procedural learning supported learning in the particular context of Côte d'Ivoire, where extraneous factors such as age at starting school and experience with the language of education may influence the impact of procedural learning on reading, and 2) the appropriate methods of measuring declarative learning in a context where the most widely used measures in the United States and Europe might be unreliable due to culturally-bound world knowledge and experiences. Therefore, the aims of this proposed dissertation are; to 1) understand the contributions of procedural learning to emergent reading, 2) evaluate whether different methods of measuring declarative learning are culturally sensitive and appropriate for use in contexts like rural Côte d'Ivoire, and 3) examine the relative importance of procedural and declarative learning to emergent reading in adolescence.

Given the evidence from second language acquisition research, such that older learners rely more on declarative learning as they first start to learn a second language, and the subsequent propositions of the DPM that older learners of language related skills may have competition between procedural and declarative supported learning, then the expectation should be that older emergent readers become more reliant on declarative learning to attain their new skill. To understand the potentially increasing importance of declarative learning it is necessary to first understand the role of procedural learning among children learning to read later in life, particularly how procedural learning might support skills for early emergent reading such as phonological awareness and decoding. Determining the best method for measuring declarative learning in a culturally valid way lays the foundation for a study which can compare the relative contributions of procedural and declarative learning to reading and reading related skills amongst older emergent readers in rural Côte d'Ivoire.

Chapter 2

UNDERSTANDING THE CONTRIBUTIONS OF PROCEDURAL LEARNING TO EMERGENT READING

Literacy acquisition can take place at any age: however, a changing maturational landscape of memory likely impacts the path to literacy. For many children learning to read for the first time can occur well-outside the time period of traditional reading research, when the maturational landscape has evolved from that of early childhood. The cognitive systems which support emergent reading likely also evolve. In particular, procedural learning which supports the learning of patterns and structures across multiple exposures (Morgan-Short et al., 2014; Mayor-Dubois, et al., 2016; Quam, Wang, Maddox, Golisch, & Lotto, 2018) including the formation and application of phonological categories. Procedural learning is associated with implicit learning that underlies automatic, subconscious knowledge (Squire 1992; Squire & Zola, 1998; Squire et al., 2004; Squire & Dede, 2015). For reading, procedural learning likely supports the development of reading adjacent skills, such as the ability to recognize the patterns of allowable sound combinations or morpheme constructions within a language (i.e., phonological awareness; Bradley & Bryant, 1983). Phonological awareness, as a subordinate category of phonological processing, underlies the phoneme to grapheme mappings required to become a skilled reader, however if, as some suggest, the role of procedural learning if skill learning decreases with age then the role of procedural learning in older emergent reading may also change, however, very little work has been done to examine this changing role.

While previous work in LMICs demonstrates that children can perform just as well on procedural learning tasks as the HIC peers (Yuan et al., 2020), it remains important to understand how procedural learning impacts emergent reading in these contexts as factors such as the age of the child at time of starting school, and the child's school attendance, may still influence the relation between procedural learning and reading, particularly as phonological processing (largely supported by procedural learning in younger children) appears to be important for readers of any age (Young-Scholten, 2015). For children growing up in the United States, lower school attendance has been linked to poorer reading (Chatterji, 2006). Additionally, amount of reading exposure is linked to later reading outcomes (Leppänen et al., 2005; Harlaar et al., 2007) and when learning to read in a second language, earlier versus later age of acquisition can lead to differences in reading processing, such that words from the second language which were learned earlier are read faster by children than words for the second language which were learned later (Dirix & Duyck, 2017). In Côte d'Ivoire, where school absences are a pervasive issue and later age at starting school (see The Study Context, in chapter one) means an older age of acquisition for both reading and the language of instruction, the question of how age of reading acquisition will impact the influence of procedural learning on children learning to read remains unclear.

Procedural learning supports the discovery of relationships and structures (i.e., phonological structure) through the refinement of predictions in the pattern learning (Hedenius et al., 2012; Ullman, 2004; Ullman et al., 1997; Ullman & Lovelett, 2018). These refined predictions, in turn support the formation of habits and skills which rely on stable representations derived across multiple exposures. For example, the unique sound pattern of a single word has an arbitrary relationship to its referent, learned through inferences drawn from experience. Learning the phonological patterns, or phonotactics (e.g., rules related to the permissible combinations of sounds and syllables in a language), across many words emerges through the implicit recognition of patterns (Avcu et al., 2019). This capacity to generate expectations for sequenced events (i.e. repeat exposures) in procedural learning is thought to account for the human language ability to predict what sounds should, and can, co-occur (Cohen, Poldrack, & Eichenbaum, 1997; Conway & Pisoni, 2008; Goschke, Friederici, Kotz, & Van Kampen, 2001; Warker, 2013). The predictions of common sound patterns in language facilitates the ability to map phonemes to their orthographic representation (Apel et al., 2006), therefore, it is likely that procedural learning plays a role in emergent reading acquisition as skills often associated with procedural learning have been linked to reading acquisition.

Aspects of procedural learning have been closely linked to reading; one ability often linked to procedural learning, statistical learning, is a predictor of early reading (Arciuli & Simpson, 2012; Qi et al., 2019; Torkildsen et al., 2019; Zinszer et al, 2021). While implicit statistical learning has been linked to declarative-related systems (Schapiro & Turk-Browne, 2015), the engagement of procedural learning in statistical learning tasks appears to stem from the participant's abilities to make predictions (see Overall Goals for further discussion; Erickson & Thiessen, 2015; Karuza et al., 2013; Ceballos et al., 2020). Visual statistical learning was related to reading in both children (age 9) and adults (Arciuli & Simpson, 2012), indicating that for even older and more skilled readers implicit learning abilities contribute to reading. Auditory statistical learning was also related to reading for non-words and this relationship was mediated by phonological processing (Qi et al., 2018), indicating that implicit learning's contribution to reading skills are through its support of phonological processing abilities and, by extension, phonological awareness.

Further evidence of this link from procedural-supported statistical learning to reading comes from the finding that after several days of training with feedback for reading real words, children age 7 attending school in the United States were better able to learn the phoneme-to- grapheme relationship for vowels when they were exposed to these vowels in a greater variety of contexts (Apfelbaum et al., 2013). The results of Apfelbaum et al. (2013), indicate that the ability to acquire the phoneme-to-grapheme knowledge which underlies basic decoding skills can be supported through implicit learning. Implicit learning, which occurs across many exposures, is a characteristic of procedurally-supported learning. Indeed, the ability to map graphemes to the phonemes they represent has been linked to greater activation of procedurally-related areas such as the basal ganglia and inferior frontal gyrus (McNorgan et al., 2011). Importantly, the Apfelbaum et al. (2013) also found a difference in the importance of this implicit learning across multiple exposures between real words and non-words such that variability in consonant context was related to better vowel learning in non-words compared to real words which indicates that decoding is the exclusive strategy for reading non-words but not real words (Apfelbaum et al., 2013). For even relatively inexperienced readers, therefore, real words might also be recognized as whole words, which are mapped to preexistent meanings stored in decorative memory, meaning that procedural learning is not always the system that supports all aspects of early reading.

The two paths to reading for real words reflects the potential two paths through emergent reading, one through procedurally learning potentially most common for younger emergent readers, and the other through declaratively learning potentially the common path for older emergent readers. However, the system which supports emergent reading is not necessarily exclusively influenced by age. As skill level increases, reading becomes less reliant on procedurally learning. Emergent readers rely more heavily on phonological information when first learning to, but as emergent readers become more skilled, this reliance on orthography to phonology to semantics shifts towards a greater reliance on vocabulary knowledge and to a more direct orthography-semantic mapping (Cain & Oakhill, 2014, Harm & Seidenberg, 2004). As very little work has yet examined emergent reading beyond childhood, it is difficult to untangle the role that memory maturation might play in the transition from the importance of procedurally learning to declarative learning observed in more skilled (and also older) readers.

Multiple studies suggest that procedural learning reaches developmental maturity in childhood at some point around the beginning of adolescence (Finn et al., 2016; Mayor-Dubois et al., 2015). However, several developmental differences can impact the maturation of procedural learning, including Williams syndrome (Vicari et al., 2001), specific language impairment (Lum et al., 2014), and dyslexia (West et al., 2019; Nicolson & Fawcett, 2019; Lum et al., 2013). Handwriting difficulties have been linked to poorer procedurally-supported motor learning in children with attention deficit disorder (Duda et al., 2019). Additionally, in typically developing children, it has been reported that while older children (11-12 years) and younger children (6-8 years) both have similar procedural learning capacities, older children learn the patterns more rapidly (Magallon, Narbona, & Crespo-Eguílaz, 2016). Improvement in performance on tasks designed to measure procedural learning may indicate factors which contribute to rapid skill learning, such as processing speed, are still developing even when procedural learning is mature (Zinszer et al., 2021).

Other cognitive abilities, such as inhibitory control, may also differentially contribute to skill learning as children develop nascent cognitive skills (Lejeune, Catale, Schmitz, Quetemont, & Meulemans, 2013). Indeed, some point to the protracted development of cognitive abilities such as attention and working memory to explain the early dependence on implicit/procedural learning. Immature attention and working memory lead to limited encoding of smaller grain sized units in which the structural patterns are more salient. As the attention and working memory capacities increase, the ability to encode larger chunks of information is supported by declarative learning and patterns within this information may be harder to identify (Smalle et al., 2017; Finn et al., 2014) Younger children, who have short working memory spans and poorer attention, may by necessity focus on smaller grain sizes and therefore are more able to learn new phonological information (Newport, 1993; Young-Scholten & Naeb, 2010). The reliance of younger children on smaller chunks of information potentially explains the importance of procedural learning in early childhood skill acquisition.

Among children growing up in low-resource, low-literacy environments, the development of procedural learning as with other cognitive skills may be influenced by a child's experiences with formal education (Sharp et al., 1979). This is particularly relevant in contexts such as rural Côte d'Ivoire where schooling is often interrupted and both children and teachers are frequently absent. Children in rural Côte d'Ivoire are often approaching or within early adolescence when the receive their first experience with literacy, meaning that, not only is procedural learning decreasing in importance for skill learning, but the interrupted and reduced experience with phoneme to grapheme mapping may not be sufficient to develop procedural representations to support emergent decoding. Procedural learning aids the development of phonological awareness, a crucial skill for early reading, potentially emergent reading may be less successful among children whose emergent literacy is less reliant on procedural learning, therefore, the older the age of the learner, the weaker the relationship between procedural learning and reading. The uncertainty surrounding the role of procedural learning in older emergent reading gives rise to two competing hypotheses; 1) procedural learning may contribute differently to emergent readers as a learner ages. Age will moderate the relationship between procedural learning and emergent reading. Specifically, older children will have a weaker relation between procedural learning and emergent reading. Or, (2) procedural learning supports emergent reading and this relationship is stable over development and not moderated by an emergent reader's age. Given the above, procedural learning contributes to the development of early reading, however, the extent to which this contribution can succeed among older emergent readers in LMICs such as Côte d'Ivoire remains, as yet, undetermined.

2.1 Experiment 1

If the changing maturational landscape of memory impacts the path to literacy, it is vital that the nature of this impact be fully tested and explored among children who learn to read later in life. Particularly, previous research in HICs suggests that the phonological understanding of language which is purported to be supported by procedural learning is vital for early reading, leading to the question; Does procedural learning support phonological awareness in adolescent emergent readers? This study evaluates two competing hypotheses; (1) Procedural learning may contribute differently to emergent readers as a learner ages. This hypothesis would predict that emergent reading will be dependent on procedural learning for younger children, but that for children who were older when they first began learning to read, emergent reading and the associated skills (i.e., phonological awareness) may depend less on procedural learning.

Specifically, older children will have a weaker relation between procedural learning and emergent reading. Alternatively, (2) emergent reading at any age relies similarly on procedural learning. This hypothesis would predict that procedural learning, as the system which, in part, supports phonological processing and by extension phonological awareness, will be a vital predictor of reading for both older and younger children who are at a similar skill level (i.e., in emergent stages of reading). That is, the predictive relation between procedural learning and emergent reading skill is consistent over development and is not moderated by an emergent reader's age.

To adjudicate between these hypotheses, this proposed chapter will examine the relation between procedural learning, language skills, age, and literacy in 5th grade emergent readers. As many children in rural Côte d'Ivoire struggle to decode words even after reaching the equivalent of the 5th grade, this study evaluates emergent reading despite the grade level of the participants. Indeed, the motivation of this study is to address the struggle of primary school children to successfully acquire reading in spite of attending and progressing through school, something which very little empirical work has examined. Understanding the contributions of procedural learning to reading in older emergent learners with age will lay the groundwork to assess the potential competition from more mature declarative learning abilities as suggested from findings in both impaired reading development and second language acquisition. Further, understanding how a child's cognitive development impacts their reading development is vital in order for the study of reading to address the experiences of millions of children around the world who learn to read later in childhood. Finally, a greater understanding of how older emergent readers learn to read may help inform intervention efforts which will better address the needs of older emergent readers.

2.1.1 Participants

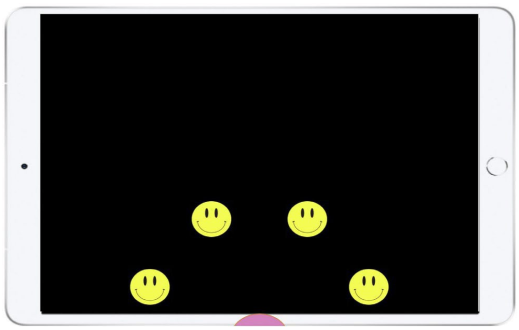
Fifty children in the equivalent of fifth grade (the second to last grade before graduating primary school) from 6 French monolingual schools in the Adzopé region of Côte d'Ivoire participated in this study. Two of these children were excluded due to experimenter error. Two children did not complete the reading measures. The ages of the remaining children were 9-15, the average age 11.27 years, SD=1.35 (Boys: N=19, M=12.05, SD=1.43; Girls: N=26, M=10.69, SD=0.97). Children with any overt developmental disorders were excluded. The age at which the children began school was calculated by subtracting the child's years in each grade (including grade repetitions) from the child's current age. Average age for a child to begin school was 5.8 years (SD=1.20) with a range from 4 to 9 years of age (Boys: M=6.32, SD=1.29; Girls: M=5.42, SD=0.99). Finally, 17 children reported speaking French in their home.

2.2 Materials

2.2.1 Procedural learning task.

The serial reaction time task (SRTT) has been widely used as a measure of learning supported by procedural learning (Nissen & Bullemer, 1987; Desmottes, Meulemans, & Maillart, 2016; Willingham, Nissen, & Bullemer, 1989; Bogaerts, Szmalec, Hachmann, Page, & Duyck, 2015; Clark & Lum, 2017a; Clark & Lum, 2017b; Earle et al., 2020; Hunt & Aslin, 2001). A keyboard-based SRT task from Lum et al. (2012) was adapted for use on a tablet. To accommodate the use of a touchscreen, an arc array as designed by Hunt and Aslin (2001) was used (see Figure 2.1). During the task, a target appears in one of several locations arcing around a central point. Targets were smiley faces appearing in one of four locations on the screen of a tablet, in an arc around a central sticker at the base of the tablet, see Figure 2.1. As the smiley face appeared in one of the four locations, the child was instructed to tap that face as quickly as possible with their fingertip. In between touching the smiley face, children were instructed to return their fingers to the sticker, or "home." During the first random block, training and scaffolding was provided by the researcher, according to the child's needs. Children were reminded to touch the faces as fast as possible. For children who required more assistance, an experimenter would hold their hands and help them to touch the first few faces to illustrate the procedure. The task (including the first few scaffolded trials) began with 40 trials (Block 1) of the smiley face appearing in a random location. Next, 320 trials (Blocks 2-9) with the smiley face appeared in a sequence of positions where the transitional probability between positions was reduced from four possible positions (25%) to three possible positions in every trial (33%) by excluding the previous position. The sequential trials were followed by another 80 trials (Blocks 10 and 11) of the smiley face appearing in a random location. Children who have learned the sequence in Blocks 2-9 will predict the next location of the smiley face based on that learned sequence, and decrease their reaction time over the sequenced blocks. When the learned sequence no longer applies (i.e., Block 10), children may continue to make predictions as if the smiley face was still following the sequence and thus increase their reaction time for the random blocks. The change in reaction time from the last block of the sequenced trials (Block 9) to the block of random trials (Block 10) provides a measurement of procedural learning.

Figure 2.1: Example of the SRTT array



2.2.2 Phonological Awareness

The phonological awareness tasks consisted of two components, 1) initial phoneme deletion (BELEC; Mousty, Leybaert, Alegria, Content, & Morais, 1994; Ball et al., 2022), where the experimenter read a word to a child and asked the child to repeat the word without the initial sound (e.g., 'cat' without the 'c' is pronounced 'at'), and 2) segmentation of French words (Yopp, 1995), where the experimenter read a word to a child and asked the child to repeat each sound of the word individually (e.g. 'book' is /b/,/ʊ/,/k/).

2.2.3 Vocabulary

Vocabulary scores were also calculated from two component parts; synonym generation and antonym generation. These tasks had been translated and abbreviated from the third edition of the Woodcock-Johnson test of cognitive abilities for use in Côte d'Ivoire (WJ-III-COG; Woodcock, McGrew, & Mather, 2001; Jasińska et al., 2020; Ball et al., 2022). Each task consisted of 5 items. For the synonym task, children were asked to provide a synonym for common French words (e.g., ‘mère,’ meaning mother and ‘maman,’ meaning mom). For the antonym task, children were asked to provide an antonym for common French words (e.g., "content," meaning happy and "triste," meaning sad)

2.2.4 Literacy Measures

Literacy measures were timed letter reading, word reading, and nonword reading tasks from the Early Grade Reading Assessment (EGRA; RTI International, 2009; Gove & Wetterberg, 2011) previously used in Côte d’Ivoire (Ball et al., 2022; Sobers et al. 2021; Zinszer et al., 2023). All of these tests were timed by experimenters with a cut-off beyond 60 seconds, as per EGRA testing protocol. For letter reading, children read 100 French graphemes and grapheme clusters (e.g., ‘e’, ‘m’, and ‘ch’) as quickly and as accurately as possible with experimenters marking incorrect responses. Word reading consisted of 50 French words (e.g., “monde”, “kilo”). Nonword reading consisted of 50 pseudowords which conformed to French phonotactics (e.g., “toche”, “donré”).

2.2.5 Socioeconomic checklist.

Children were asked about items in their home (e.g., refrigerator, books, or motorcycle). The checklist was adapted from the EGRA (RTI International, 2012) and previously used in Côte d’Ivoire (e.g. Ball et al., 2022). There was a total of 15 items. An SES score was derived from the sum of the items present in the child’s home. Using a checklist of household items rather than alternative measures of SES (e.g., maternal education or household income) is a preferable indication of the relative status of households in agricultural communities where income can vary with the seasons (Howe et al, 2012).

2.2.6 Protocol

IRB approval for the study was obtained by the University of Delaware.

Approval for the research program was also obtained from the Ivorian Ministry of Education. Consent was obtained from school directors, village chiefs, and the parent representative group (COGES); see Jasińska and Guei (2018) for detailed information about community consent procedures developed for the Ivorian context. Data collection was scheduled to suit the schedule of the village and the school.

All experimenters were fluent speakers of Ivorian French. Testing took place on school property outside the child's classroom. After assenting to take part in the study, children completed all tasks for the current study (SRTT) as well as the larger literacy intervention (demographic questionnaires, language and literacy assessments) during their normal school hours. The entirety of testing lasted for roughly two hours per child. For tasks included in this study the testing time was roughly one hour. Children received a small gift (e.g., a book) for their participation.

2.2.7 Statistical Analysis

For the SRTT task, reaction times were log transformed. Inaccurate trials were discarded (M=0.02% of trials, SD=0.04%, range= 0-16%). In the 9th and 10th block two subjects had over 15% errors. These two children were removed from further analysis. Trials with reaction times three standard deviations above or below the mean for each individual child were also discarded (M=2.66%, SD=0.93%, range=0.31-5.31%). The procedural learning score was determined by subtracting a child's mean reaction time in the 9th block (the final sequenced block) from their mean reaction time in the 10th block (return to random pattern after sequenced).

Statistical analysis was conducted using R Studio (RStudio Team, 2015. Data cleaning and transformation were conducted using the R packages 'plyr' (Wickham, 2011) and 'tidyverse' (Wickham, 2019). Correlations for testing the relationship between age or grade repetition to other variables such as language, literacy, or procedural learning were conducted using the R package 'psych' (Revelle, 2019). Regressions to examine the effects of age, phonological awareness, vocabulary, and procedural learning on reading were also conducted using the R package 'stats' (R Core Team, 2012) and 'lm.beta' (Behrendt, 2023). Variables were centered to avoid multicollinearity using the function 'scale' (R Core Team, 2012). Simple slope analysis to examine interactions between continuous variables and the visualization of this interaction was generated using the R package 'interactions' (Long, 2019). Other visualizations were generated using the 'ggplot2' (Wickham, 2016) and 'ggpubr' (Kassambara, 2020) packages. Variables were centered to avoid multicollinearity. With centering, variance inflation factor (VIF) for all variables was under 2.5 (Thompson et al., 2017).

2.3 Results

I first present descriptive results for each measure: age (and age at school start, and grade repetition), procedural learning, language (phonological awareness, vocabulary) and reading (letter, word, nonword reading) as well as the statistical relationships between these measures. I unpack the complex role of age in this sample by examining the factors related to being an older age learner (i.e., age at school start and grade repetition) and the statistical relationships between age and reading and reading-related skills (i.e., phonological awareness and vocabulary). These relationships were tested by Spearman correlation as these are better suited for non-normally distributed data (Zimmerman & Williams, 1997). Finally, I conduct a regression model testing the main effects and interactions between age, procedural learning, and language, and reading skills.

2.3.1 Age at School Start and Grade Repetition.

Both age at which children started school and grade repetitions contributed to the variability in age in 5th graders. That is, a child who started school later would be older in 5th grade, and similarly a child who repeated grades would also be older in 5th grade. 2.1. Unsurprisingly, age at time of testing and age at school start were highly correlated with one another, but age at school start and grade repetition were not correlated ($p=.60$), see Table 2.2. Some older children were older when they started school, the average age of starting school for children ages 11-15 was 6.27 compared to 4.79 for children aged 9-10.

Overall, the average number of grade repetitions was 0.48 (SD=0.59), with some children never having repeated a grade, while others repeated one to two times. Among the oldest children (ages 11-15) grade repetition was higher (M=0.60; SD=0.62), whereas among the youngest children (ages 9-10); grade repetition was lower (M=0.21; SD=0.43), this difference was significant (t(35.82)=2.40, p=.02). SES was not correlated with grade repetitions (p=0.12)

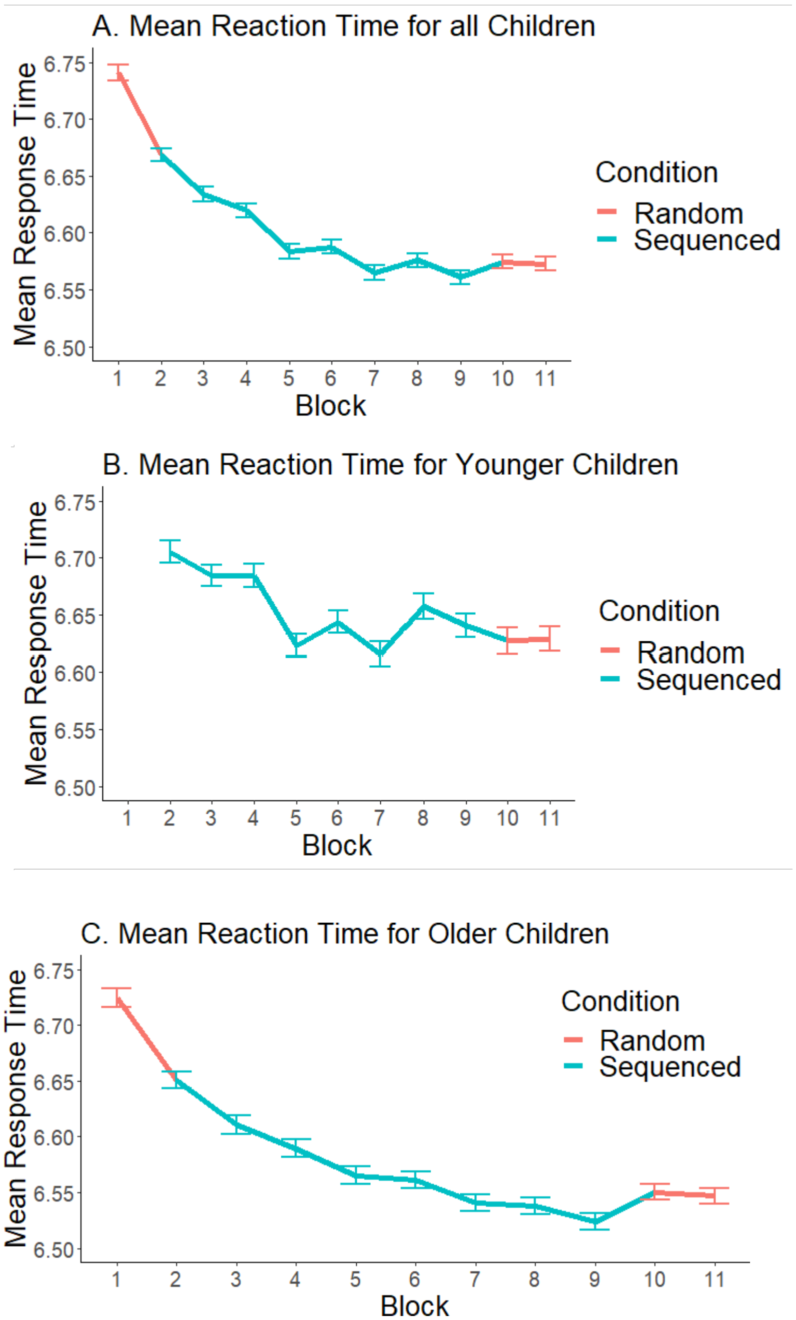
2.3.2 Procedural Learning.

Children became faster as they learned the sequence. The first and last sequence blocks (2 and 9) were significantly different according to a paired sample t-test (t(43)=5.51, p<.001). Procedural learning was positively correlated with age; see Table 2.1). Figure 2.2B and 2.2C shows procedural learning of younger and older children.

Table 2.1: Means and Standard Deviations for all measures.

Measure	M	SD
Age (9-15)	11.25	1.37
Age at School Start (4-9)	5.80	1.21
Grade Repetition (0-2)	0.48	0.59
SES (0-15)	4.95	2.40
Phonological Awareness (0-10)	2.82	2.97
Procedural Learning	0.01	0.10
Vocabulary (0-10)	3.23	2.07
Letter Reading (0-100)	29.32	21.70
Word Reading (0-50)	14.5	15.96
Nonword Reading (0-50)	9.86	12.01

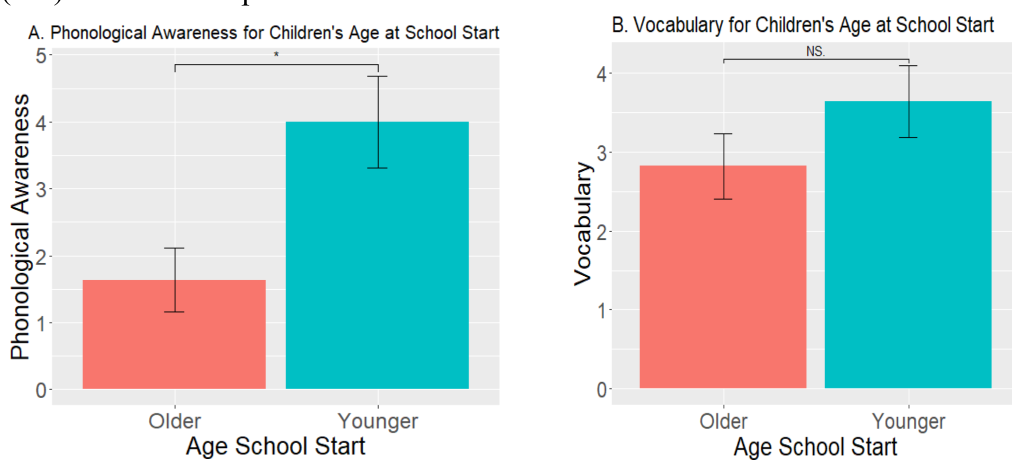
Figure 2.2: A. The mean reaction time for the SRTT at each block. B. The mean reaction time for the SRTT at each block for younger children. C. The mean reaction time for the SRTT at each block for older children. Error bars represent standard error.



2.3.3 Language

Speaking French in the child's home was not correlated with, phonological awareness, vocabulary, letter reading, word reading, or non-word reading. Phonological awareness was negatively correlated with age ($\rho(42)=-.36$, p=.02; see Table 2.2) and with age at school start ($\rho(42)=-39$, p=.009), but not correlated with grade repetition (p=.73). Vocabulary scores were not significantly correlated with age (p=.95), age at school start (p=.68), or grade repetition (p=.61; see Table 2.2). Further, children were divided by median split into groups for older and younger age at school start (Older: 6-9; N=22; Younger: 4-5; N=22). A t-test found that phonological awareness was significantly different between these groups (t(37.33)=-2.84 , p=.007; see Figure 2.3A), but vocabulary was not (p=.19; see Figure 2.3B).

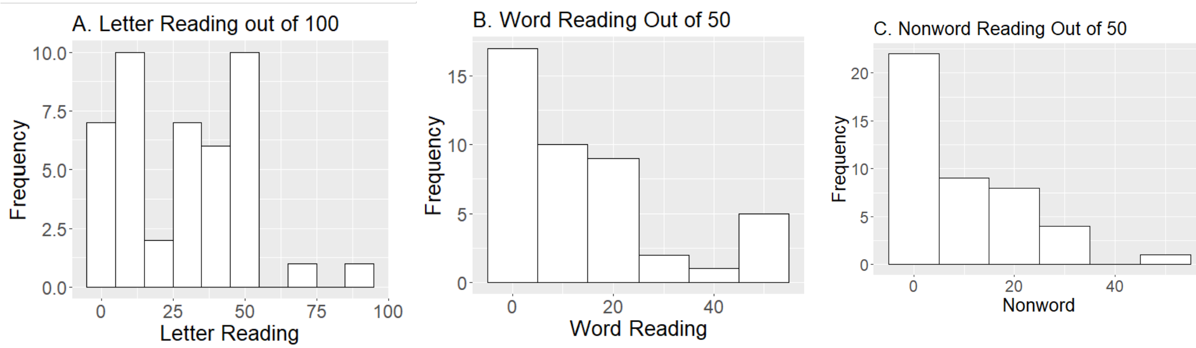
Figure 2.3: A. Bar plot of phonological awareness for age at school start; older (6-9) vs. younger (4-5). B. Bar plot of vocabulary for age at school start; older (6-9) vs. younger (4-5). Error bars represent standard error.



2.3.4 Reading

Reading scores were low overall, see Table 2.1. Word and nonword reading scores were positively skewed (1.09, 1.22, respectively), reflecting the emergent reading levels of the sample, see Figure 2.4. Each reading test was correlated with phonological awareness and vocabulary; see Table 2.2). Reading scores were not correlated with age or year of school but older children tended to be poorer reader (see Figure 2.5).

Figure 2.4: A. Histogram of Letter Reading scores. B. Histogram of Word Reading scores. C. Histogram of Nonword Reading



scores.

Figure 2.5: A. Scatterplot of percent correct for reading scores across three reading tests (Letters, Words, and nonwords) for age at time of testing. B. Scatterplot of percent correct for reading scores across three reading tests for age at school start.

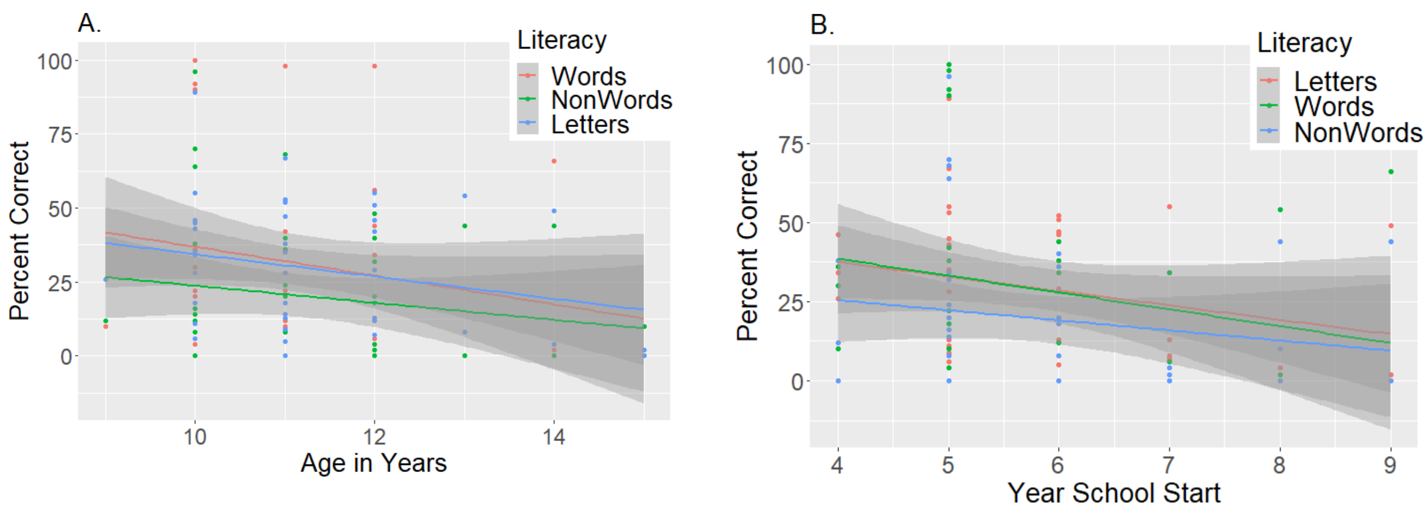


Table 2.2: Spearman correlation without corrections.

	1	2	3	4	5	6	7	8	9
1. Age									
2. Year of School Start	.85***								
3. Grade Repetition	.41**	-0.06							
4. SES	-0.1	-0.14	0.25						
5. Phonological Awareness	-.30*	-.35*	-0.01	0.02					
6. Vocabulary	0.07	-0.03	-0.02	-0.2	.47**				
7. Procedural Learning	0.15	0.13	0.15	0.02	-0.2	-0.17			
8. Letter Reading	-0.15	-0.24	-0.07	-0.16	.45**	.52***	-.33*		
9. Word Reading	-0.19	-0.28	-0.08	-0.07	.60***	.45**	-.40**	.78***	
10. Nonword Reading	-0.12	-0.16	-0.09	0.02	.53***	.47***	-.31*	.70***	.85***

Note. * indicates $p < .05$. ** indicates $p < .01$.

2.3.5 Procedural Learning and Reading

A multiple linear regression estimated the effect of phonological awareness, vocabulary, procedural learning, socioeconomic status, age at school start, and grade repetition, and interactions between age and procedural learning, procedural learning and phonological awareness, and procedural learning and vocabulary on letter, word, and nonword reading.

There were significant main effects of phonological awareness and vocabulary for letter reading. Higher phonological awareness and vocabulary scores were associated with better letter reading scores. There were also significant interactions between procedural learning and phonological awareness and between procedural learning and vocabulary, see Table 2.3. For word reading, there was a main effect of phonological awareness. Higher phonological awareness scores were associated with better word reading scores. For nonword reading, there was a significant main effect of phonological awareness and marginal main effects of procedural learning and vocabulary. Higher phonological awareness and vocabulary scores were associated with better nonword reading scores. There was a marginal interaction between procedural learning and phonological awareness, see Table 2.3.

The interaction between phonological awareness and procedural learning was further evaluated using a simple slopes analysis (Aiken & West, 1991; Hughes, 2020; Figure 2.6A). This analysis examined the significant two-way interaction of two continuous variables by controlling for one of the variables and then measuring the effect of the other variable at different levels as determined by one standard deviation above and one standard deviation below the mean (Preacher, Curran, & Bauer, 2005; Aiken & West, 1991). For children with higher procedural learning scores (one standard deviation above the mean), phonological awareness significantly predicted letter reading ($b=0.89$, $t(34)=3.94$ $p<0.001$). For children with lower procedural learning scores (one standard deviation below the mean), phonological awareness did not predict letter reading ($b=-0.28$, $t(34)=-1.34$, p=0.19). The relation between phonological awareness and reading, therefore, was stronger for children with higher procedural learning scores.

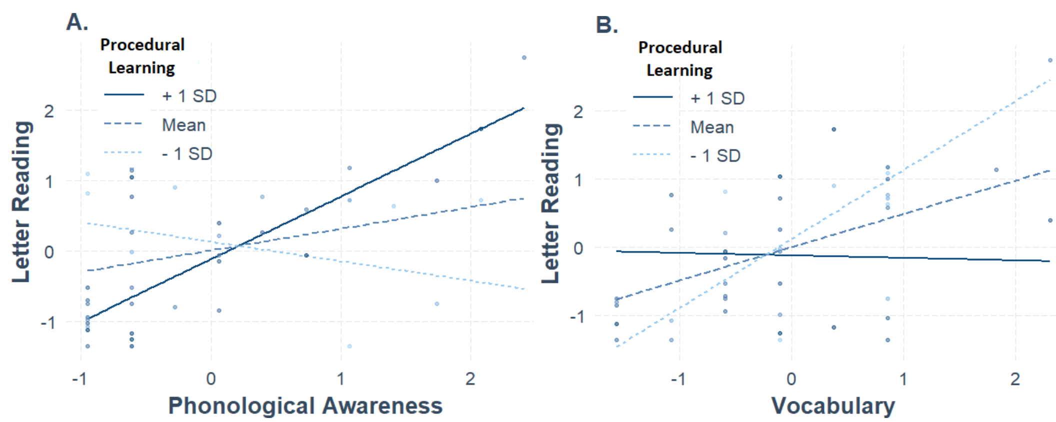
The interaction between vocabulary and procedural learning was also further evaluated using a simple slopes analysis, see figure 2.6B. For children with higher procedural learning scores (one standard deviation above the mean), vocabulary did not significantly predict letter reading (b=-0.03 t(34)=-0.13, p=.90). For children with lower procedural learning scores (one standard deviation below the mean), vocabulary did significantly predict letter reading (b=1.01, t(34)=3.43, p<.001).

Table 2.3: Regression results predicting variations in letter, word, and nonword reading.

	Letter Reading	*Word Reading*	*Nonword Reading*
Predictor	β	β	β
Socioeconomic status	-0.01	0.05	0.13
Age at School Start	-0.05	0.10	0.16
Grade Repetition	-0.08	0.01	-0.13
Procedural Learning	-0.12	-0.19	-0.24 .
Phonological Awareness	0.31*	0.59***	0.58 ***
Vocabulary	0.49***	0.22	0.26 .
Age: Procedural Learning	0.08	0.03	0.08
Procedural learning: Phonological awareness	0.58**	0.19	0.31 .
Procedural learning: Vocabulary	-0.52*	-0.26	-0.32
Fit	R^2= 0.60 *** Adjusted R^2= 0.50	R^2= 0.56 *** Adjusted R^2= 0.44	R^2= 0.60 *** Adjusted R^2= 0.49

. *indicates p<.1 * indicates p < .05. ** indicates p < .01.* *** indicates p<.001

Figure 2.6: A. Simple slope analysis of letter reading's relation to phonological awareness at different levels of procedural learning. B. Simple slope analysis of letter reading's relation to vocabulary at different levels of procedural learning.



2.4 Discussion

This study examined the relation between procedural learning and emergent reading in late childhood and adolescence. Specifically, focusing on a low-literate, rural region of Côte d'Ivoire with a high rate of illiteracy, where the age at which a child enters school is highly variable. Consequently, children of very different ages learn in the same classroom. Despite reaching the fifth grade, the children in this study largely remained in an emergent stage of reading development (i.e., struggling to decode words; Heugh, 2011). Older children (ages 11- 15) demonstrated better procedural learning than younger children (ages 9-10), suggesting age- related variation in procedural learning among children in the same classroom. Older children had poorer phonological awareness, a crucial skill for emergent reading. Overall, average performance on the letter, word, and nonword reading task was low, at 29.76, 30.91, and 20.17, percent correct, respectively. Many children struggled to decode a single word or nonword and remained in the emergent reading stage despite being in the fifth grade. The apparent disadvantage for reading among children who have been in school for at least five years highlights the importance of reading research in contexts where children learn to read late. These findings indicate that the relation between phonological awareness and reading, and vocabulary and reading among children aged 9-15 depends on procedural learning.

Supporting the second hypothesis, the relevance of procedural learning to reading was unrelated to the child’s age. The interaction of procedural learning on the relationship between phonological awareness and reading was observed. Importantly, the positive relation between phonological awareness and reading was significant for children with better procedural learning, but not for children with poorer procedural learning. This suggests that procedural learning supports the skills vital for reading development and that the children who were able to leverage this support were more able readers. The above results suggest a more complex account of the relationship between developing memory and emergent reading throughout childhood.

Previous work, from HICs and LMICs alike, has outlined the importance of phonological awareness for emergent (typically younger) readers and the increasing importance of vocabulary for skilled (typically older) readers (Jasińska & Petitto, 2018; Tannenbaum, Torgesen & Wagner, 2006; Jasińska et al., 2019). However, while previous work almost exclusively examined emergent reading in younger children, here, language skills similarly relate to emergent reading for both older children and adolescents. Phonological awareness and vocabulary were both positively related to reading in this sample of 5th grade children and adolescents. Phonological awareness was related to letter, word, and nonword reading, suggesting that phonological awareness supports phoneme-to-grapheme mapping for emergent readers in low-literacy communities. Vocabulary was related to letter and nonword reading (marginally). This was a somewhat surprising result: word knowledge is not expected to be helpful for reading words that do not actually exist (Ricketts, Nation, & Bishop, 2007). However, it should be noted that nonword reading scores were extremely poor, and therefore, only the best readers scored well in the nonword reading task. These stronger readers also showed overall higher language skills (i.e., high scores in phonological awareness and vocabulary tasks), and importantly nonword reading was highly correlated with both phonological awareness and vocabulary. Therefore, the marginal relation between vocabulary and nonword reading may be a proxy for overall language skills and nonword reading.

2.4.1 Procedural Learning

The measure of procedural learning used in this study, the SRTT task, has been widely used in both children and adults, and previous work suggests that the development of procedural learning is largely similar in LMIC and HIC contexts (Kolling, Graf, & Knopf, 2016)). The age invariance for procedural learning tasks performance has been supported by multiple studies suggesting that procedural learning reaches developmental maturity in childhood at some point around the age of 10 (Finn et al., 2016; Mayor-Dubois et al., 2015). For children between 9-15 years of age growing up in rural Côte d'Ivoire, however, there was an age-related improvement in procedural learning performance. Older children (11-15 years) showed faster reaction times over the duration of the SRTT paradigm’s sequenced trials. Older children also showed slower reaction times when sequence trials switched to random trials–indicating that they had learned the sequence; and older children demonstrated a greater difference in response time between random trials and sequenced trials in the SRTT task. Improvement in performance of the SRTT may indicate more gradual skill development with age such as processing speed (Zinszer et al., 2023). Other cognitive abilities such as inhibitory control may also differentially contribute to procedural learning as children develop, which highlights the importance of further work to evaluate the development of these factors in children in contexts like Côte d'Ivoire (Lejeune, Catale, Schmitz, Quetemont, & Meulemans, 2013). Additionally, the results corroborate previous reports that while older children (11-12 years) and younger children (6-8 years) both have similar procedural learning capacities, older children learn the patterns more rapidly (Magallon, Narbona, & Crespo-Eguílaz, 2016). Given enough time and a sufficient number of trials, then, older and younger children might eventually perform very similarly on the SRTT, though such an experiment would be prohibitively long. Nevertheless, the above findings for procedural learning in Côte d'Ivoire suggest at least some level of developmental differences in procedural learning present among children who are in the same classroom receiving the same reading instruction. Importantly, the results highlight the value of research conducted outside of HICs contexts for developing universal models of memory development.

2.4.2 Reading in Côte d'Ivoire

In this study, fifth grade children ranged in age from 9-15 years, therefore, children in the same classroom receive the same pedagogical content and learning support despite being of a different age. Understanding the specific role of procedural learning in reading development is then very relevant for appropriately addressing the issues facing older children learning to read for the first time.

Older children demonstrated poorer phonological awareness skills in comparison to younger children. The relation between reading and phonological awareness is reciprocal, not only does phonological awareness contribute to skilled reading, but skilled reading also supports phonological awareness. As a child learns to read, their metalinguistic knowledge of language increases, therefore better phonological awareness leads to better reading and better reading leads to better phonological awareness (Castles & Coltheart, 2004; Hogan, Catts, & Little, 2005; Wagner & Torgesen, 1987). Older children may then demonstrate poorer phonological awareness because they are poor readers.

Additionally, the disadvantaged phonological awareness for older children is likely a function of educational environment factors, such as starting school late or repeating grades (Whitehead et al., 2023; Wortsman et al., *under review*). Unsurprisingly, children who are older in the fifth grade were older when they started school. Late age at school start likely reflects factors associated with a child’s home environment (i.e. child labor, parental illiteracy, poor home literacy environment), which contribute to poorer academic outcomes. The quality of the home reading environment and amount of reading exposure has been linked to reading outcomes (Dong et al., 2020; Georgiou et al., 2021; Leppänen et al., 2005; Harlaar et al., 2007). If the child's home reading environment is poor (i.e. no literate adults in their family, no access to books) then a later age at school also corresponds to later first exposure to reading.

Importantly, many children who participated in this study do not speak French as a first language and their exposure to French began when they started school, (Ayewa, 2018; Brou- Diallo, 2011) albeit this is five or more years ago for all children in the study. Later age at school entrance therefore means a later start in learning French, contributing to lower phonological awareness and reading scores. For children learning to read in a second language, earlier versus later age of acquisition is related to better reading. For example, children read words faster in an earlier-learned versus later-learned second language (Dirix & Duyck, 2017). In this study, however children's reports of speaking French in their home, thereby indicating that they were exposed to French prior to entering school, was not related to any language or literacy measures.

Interestingly, a later age of school start was only negatively related with phonological awareness, but not vocabulary. The importance of early language exposure for phonological awareness fits well with existing language acquisition research on sensitive periods for the acquisition of phonology (Newport, 1993; Young-Scholten & Naeb, 2010; Hammick et al., 2018; Legault et al., 2018; Tarone, 2010; DeKeyser, 2008; Young-Scholten & Naeb, 2010; Grenfell & Harris, 2015). Specifically, as individuals age, the ability to learn phonology and syntax diminishes, while the ability to learn new vocabulary remains (Birdsong, 2018). Finding a significant relation between age and phonological awareness, but not between vocabulary and age, supports an earlier advantage for acquiring phonology.

Nonetheless, phonological processing appears to be important for readers of any age (Young-Scholten, 2015). The relation between phonological awareness and reading was stronger for children with better procedural learning, suggesting that procedural learning supports the skills vital for emergent reading. In contrast, the relation between vocabulary and reading was weaker for children with better procedural learning. That is, procedural learning had an opposite moderating effect on the relation between vocabulary and reading, compared to phonological awareness and reading. This suggests that vocabulary skills may be more relevant to emergent reading for children with poor procedural learning, and for whom explicit word knowledge rather than implicit decoding offers an alternate route to reading. The relation between vocabulary and reading corroborates recent work from Côte d'Ivoire which found that 6th grade children between 10-18 years of age relied more on their semantic knowledge of French for reading instead of their knowledge of grapheme-to-phoneme mappings (Brice et al., *in press*).

Under the framework laid out by the Declarative/Procedural Model (Ullman, 2004), procedural learning, at least in part, supports phonological awareness skills. The procedural learning system, as the system which supports phonological processing more generally, would also support a specific aspect of phonological processing, phonological awareness. Contrary to this framework, there was no significant correlation between procedural learning and phonological awareness. This in part might be attributed to overall low phonological awareness scores in this sample. These results suggest new directions for exploring the potential competition between declarative and procedural learning, outlined in the Declarative Procedural Model (DPM; Ullman, 2015; Ullman 2001; Ullman 2004; Ullman & Pullman, 2015; Ullman, & Lovelett, 2018). It is this competition which gives rise to the less efficient and less fluent language learning among adolescents and adults, particularly the structural aspects of language such as phonological processing and, potentially, phoneme-to-grapheme mapping. These findings suggest that learning to read at an older age may be less efficient if learning is explicit (supported by declarative learning) and suggests important avenues for future research to test the contributions of both procedural and declarative learning to emergent reading across a broad age range.

Recent research found that the earliest stages of reading development for first graders in the US was supported by declarative learning, with procedural learning becoming more important for reading among second graders (Earle et al., 2020). Earle et al. (2020) concluded that metalinguistic knowledge essential for emergent reading was first encoded with declarative learning, before becoming proceduralized. Similarly, some children in this Ivorian sample may effectively still be in the very earliest stages of emergent reading and therefore developing an understanding of the segmental nature of language by memorizing letter-to-sound mapping explicitly. During this stage, procedural learning may not yet support the automatization that is essential for reading development to continue. A child might do well in the procedural learning task and have a relatively high score but still remain a poor reader because they do not yet have the foundation of explicit knowledge of letter-sound mappings for procedural learning to build upon, and this might be observed as a negative relationship between reading and procedural learning because many children have not reached the level of explicit letter-sound knowledge at which procedural learning can start to support them. On the other hand, procedural learning does influence the relation between phonological awareness and reading such that better procedural learning was associated with a stronger relation between phonological awareness and reading. This suggests that, when controlling for skill level, better procedural learning may support the automatization of reading once children explicitly acquire letter-sound associations. Indeed, for children with poorer phonological awareness procedural learning had a negative relation to reading. This may suggest that procedural learning contributes to reading once explicit letter- sound knowledge (which is supported by phonological awareness) has reached a level of development at which it is possible to proceduralize this letter-sound knowledge and begin decoding.

Skill level in this sample has a complex relation to age as older children were both better at the procedural learning task and poorer readers with poorer phonological awareness. Crucially, in HICs, age and reading skill are strongly linked, as a child ages and develops they are receiving consistent pedagogical support for their reading. In Côte d'Ivoire, children of variable ages share the same classrooms and are at the same relative stage of reading. In this context, therefore, this study can begin to decouple skill and age. While previous work has indicated the changing importance of phonological awareness and vocabulary as well as with the changing importance of declarative and procedural learning with age, there was not sufficient evidence to conclude that adolescent emergent readers do not rely on procedural learning to the same extent as younger readers. Instead, procedural learning's contributions to reading through proceduralized phonological awareness. It appears, then, that given a sufficient level of the letter-sound knowledge required for reading, procedural learning supports automatization for decoding during emergent stages of reading regardless of age, though age may impact a child's ability to reach this level of letter-sound knowledge.

Additional evidence for disentangling skill level and memory maturation comes from the moderation of procedural learning on the relation between vocabulary and reading. Vocabulary is a skill which becomes more important as reading skills develop (Cain & Oakhill, 2014, Harm & Seidenberg, 2004). Procedural learning had an opposite moderating effect on the relationship between vocabulary and reading, compared to phonological awareness and reading. Further, lower procedural learning scores were associated with a stronger relation between vocabulary and reading, but a weaker relation between phonological awareness and reading. This suggests that vocabulary skills may be more relevant to emergent reading particularly for children with poor procedural learning, and for whom explicit word knowledge offers an alternate route to reading. This result may provide tantalizing new evidence for the potential competition between declarative and procedural learning, outlined in the DPM (Ullman & Pullman, 2015). Nevertheless, the phonological/procedural pathway, and through it the automatization of decoding, supports successful reading acquisition. This was evidenced by the interaction between procedural learning and phonological awareness on the earliest skills of emergent reading (i.e., letter reading).

Crucially, these findings indicate the continued importance of phonological awareness for older emergent readers, and that the link between phonological awareness and reading depends on procedural learning. Understanding the specific role of procedural learning in reading development is then very relevant for appropriately addressing the issues for adolescents learning to read for the first time.

2.5 Limitations and Future Directions

In rural Côte d'Ivoire, the age at which a child is first introduced to reading as well as the consistency of their reading education is highly variable. Additionally, there are more than 60 different languages spoken in Côte d'Ivoire, and the majority of Ivorians either speak French as a second or speak no French at all (Madaio, 2019). Therefore, many children in Côte d'Ivoire are learning to read for the first time in their second language, a language that they may not be exposed to anywhere else but in school. Reading in Côte d'Ivoire, is then not just emergent reading at an older age, but reading at an older age in a second language. Further work should explore reading in the second language in this context.

As mentioned above in the discussion, the findings of the present study may provide new insight for the Declarative Procedural Model, which suggests that maturational timeline of procedural learning (which matures early in childhood) and declarative learning (which matures at a more protracted rate into adulthood) is the key to explain the apparent shift from procedural (implicit) learning to more declarative (explicit) learning. Specifically, declarative learning becomes more important for skill development as it matures and competes with procedural learning when the systems overlap in the skills they might support. Indeed, previous work points to the changing importance of these learning systems for reading (Earle et al., 2020). Further research should examine how more developed declarative learning may impact the learning strategies of adolescent emergent readers, testing both declarative and procedural learning's unique contributions to reading including contributions to vocabulary and phonological awareness.

2.6 Conclusion

Previous reading research has almost exclusively focused on the experiences of children learning to read for the first time around the ages of 5-7. Millions of children worldwide enter school after the age of 7. This study examined how learning development, particularly procedural learning, impacts reading development in adolescent readers. The above results suggest that procedural learning does impact adolescent emergent reading through its support of phonological awareness. Understanding the importance of procedural learning in this context provides valuable information regarding reading development beyond early childhood. This understanding is especially important since phonological awareness may be vulnerable to age and environmental factors (i.e. school entrance and school attendance) that can be exacerbated by poverty. Additionally, this study contributes to greater understanding of the relation between procedural learning and reading and reading-related language skills. Expanding the reach of reading research can provide valuable insight which can inform interventions that can help children everywhere attain reading.

Chapter 3

EVALUATING METHODS OF MEASURING DECLARATIVE LEARNING IN LOW RECOURSE AND LOW LITERACY ENVIRONMENTS

Many factors can influence an individual's performance on behavioral tests and lead to measurement error, including the socio-cultural expectations of the participants (Baumard & Sperber, 2010). Participants from any background will naturally attempt to interpret the experiment in which they are taking part and seek to understand the wishes and intent of the experimenter, and so the participant's social and cultural expectations will influence how they perform in any task (Kihlstrom, 2021; Orne, 1962). The testing procedures themselves may impact performance, particularly when test designs do not suit participants' experiences and familiarity with testing procedures. As psychological and cognitive research seeks to correct its myopic perspective by expanding research beyond the White, urban, educated, and often Western contexts, it becomes even more important to avoid a one-size-fits-all approach to research and mitigate error (Brady et al., 2018). When bringing lab methods outside the typical lab environment, therefore, it is essential to examine how capable these methods are of measuring what they purport to measure despite differences in participants' culture and experience. The following chapter will evaluate two methods of measuring an aspect of long- term memory, declarative learning, a vital component for learning. Assessments of declarative learning are often criticized as being especially vulnerable to cultural biases (Kolling et al., 2015; Less, 2012; Vaisey & Lizardo, 2010). The purpose of the following analyses is to add to this pursuit of better, more valid tests.

3.1.1 Cultural Validity in Measure of Declarative Learning

Evaluating the strength of any behavioral or psychological experiment and its content can be accomplished in several ways. Reliability is an indication that a measure will elicit similar performances consistently across time and different iterations (Sobers et al., 2023; Bentler, 2009). Validity is an indication of how well the individual elements of an assessment measure the intended component, and the validity of any experiment can be impacted by many outside factors (Drost, 2011). Cultural validity refers to the impact of a participant's socio-cultural expectations on assessment performance, such that participants may vary in their perception of test items and understanding of task goals across cultures (Kūkea Shultz & Englert, 2021; Solano-Flores, 2011; Solano-Flores & Nelson-Barber, 2001). Ecological validity refers to the relation between the cognitive abilities a participant is asked to use in an experiment and the use of those same abilities in everyday life, such that cognitive/behavioral tests which are designed for an artificial, lab context, may not reflect the participants typical cognitive/behavioral demands (Kihlstrom, 2021; Holleman et al., 2020). Both cultural and ecological validity essentially refer to the risk of measurement error from outside variables related to a participant's understanding of the task items and of the testing procedure more generally. It is possible, therefore, that noise within a sample may signal poorer cultural or ecological validity for the assessment in use, particularly when that assessment was initially designed for different populations.

Methodologies which do not consider cultural validity in every population observed may risk inaccurate observations of the relative declarative learning skills across populations, particularly since declarative learning itself is the system which supports the development of world knowledge (Kolling et al., 2016). Kolling et al. (2016) base the assertion that cultural norms impact declarative tasks on observations from several studies. Each of these studies compared the performance of infants growing up in Germany and infants growing up in rural Cameroon on declarative-related tasks of imitation. In one study, children watched the actions of a puppet, such as looking in a mirror or putting their ear to a squeaker, and, after a delay, reproduced these actions (Goertz et al., 2011; Graf et al., 2014). In another study, children mimicked similar actions of an adult

(Borchert et al., 2013). In all three studies, while German infants appeared to perform better in the imitation tasks than their peers in Cameroon, this better performance was explained by the experimenters as potentially rooted in the familiarity of the German infants with toys and adult-child interactions (Kolling et al., 2016). Indeed, when given a task that was more familiar for the Cameroonian children, recalling items for a grocery list, Cameroonian children were better able to recall task items compared to their German peers, likely because Cameroonian children help with household chores and errands to greater extent and much earlier in their development than children in Germany (Kolling et al., 2016). These findings reflect other work which suggest that cultural structures and values are reflected in the biases through which children develop abstract reasoning skills (Carstensen et al., 2019) and therefore, children from different contexts likely approach problem solving in different ways. An individual's performance on any cognitive assessment may be influenced by factors beyond what was intended in the initial design of that assessment, particularly when these assessments are used without first being evaluated for their validity in differing contexts.

3.1.2 Multifaceted Declarative Learning

The declarative system is an aspect of memory that is associated with the recollection of events and facts (Lum, Conti-Ramsden, Page, & Ullman, 2012; Squire, Stark, Craig & Clark, 2004; Takashima et al., 2006; Ullman, 2004; Ullman, 2015; Ullman et al., 1997) and the information stored in declarative learning can be encoded quickly, in as little as one exposure (Henke, 2010; Ullman & Pullman, 2015). Within the broader scope of declarative learning are the subcategories of semantic and episodic memory (Riedel & Blokland, 2015; Tulving, 1993) which support the associative learning involved in making arbitrary connections between experiences or objects (Eichenbaum, 2000; Ullman, 2004). Individually, episodic memory supports the ability to remember the time course of events and, while it is reliant on semantic memory, it emerges later in childhood than semantic memory (Tulving, 1993; Hayne & Imuta, 2011; Ghetti & Bunge, 2012). Semantic memory supports conceptual knowledge and the interrelations between concepts, including linguistic knowledge (Yee et al., 2014; Duff et al., 2020). Together, both episodic and semantic memory contribute in tandem to an individual's ability to accumulate world knowledge and ability to look back on autobiographical memories of past experiences (Cabeza & Moscovitch, 2013; Squire & Zola, 1998).

An orthogonal view of declarative learning may consider the different types of remembering supported by the declarative system and can be also categorized as two separable aspects; 1) Recall, the ability to reconstruct and restate information stored in memory, and, 2) Recognition, the ability to know when current information matches information which has been seen or heard before (Raaijmakers & Shiffrin, 1992; Ghetti & Bunge, 2012). According to some, recall is supported by episodic memory while recognition is supported by semantic memory (Tulving, 1993; Haist et al., 1992). In order to recall, however, it is necessary to recognize through semantic memory so that these recalled memories are meaningful.

The ability to recall and recognize may develop on slightly different timelines throughout childhood. For example, children improved in their ability to recognize drawings which they had seen before between the ages of 6 to 8, but the ability to recall items which they had previously described (i.e., semantically encoded item) continued to improve into early adulthood (Ghetti & Angelini, 2008). Differences in recall and recognition which have been observed between children and adults may be due to the increasing detail of newly encoded memories throughout life. For example, children’s ability to remember items was not impacted by the way in which the item was presented (i.e., a detailed picture versus written words), for adults, however, the more detailed the item the better their recollection of it (Borges et al., 1977).

When measuring declarative learning or its subcategories of episodic or semantic memory, researchers can design experiments to elicit recall, associated with episodic memory, or recognition, associated with semantic memory. A measure of recall which has been in use since the earliest days of the empirical study of memory is the paired association task (Thorndike, 1908; Madigan & O'Hara, 1992). In the paired association task, two items are presented to be encoded together (e.g., ‘Table - Song’) then, after a delay, one half of the pair is given to the participant (i.e., ‘Table’) and they are asked to recall the other half (i.e., ‘Song’;Yuan et al., 2020; Elmwood, 1997). The paired association task can be adapted to any domain; versions of the paired association task have used visual/object learning (Yuan et al., 2020; Manns et al., 2000; Mckee & Squire, 1993) and even spatial paired associations between objects and locations (Lee & Solivan, 2008; Eichenbaum & Cohen, 2014).

3.1.3 Measuring Declarative Learning

Appropriately measuring declarative learning through tasks such as paired association requires some consideration of the learnability of the task items and considerations regarding what specific aspect of declarative learning is being measured (i.e., visual or verbal; Manns et al., 2000; Cohen et al., 1997). For example, some propose that verbal paired associations which are not semantically related (e.g. ‘Dog-Candle’) versus verbal paired associations which are semantically related (e.g. ‘Dog-Bone’) differ in the aspects of declarative learning that support them such that the semantically unrelated items rely equally on semantic and episodic memory, instead of primarily on episodic memory (Elmwood, 1997).

Beyond paired association, tasks may test declarative learning skills through the recognition of objects or words seen or heard before, and these tasks must undertake similar considerations in the learnability of their stimuli. For example, some measures of declarative learning measure the recognition of objects or images, including familiar and unfamiliar objects, and such tasks have been used to demonstrate intact declarative learning in children with dyslexia (Hedenius et al., 2013). Further, formation of new declarative memories is supported not just by the scaffolding of previous experience but also by positive feedback during the learning process (Miendlarzewska et al., 2016; Lane et al., 2007). Among adults, when given explicit feedback on performance on a task that required the recognition of objects seen before and the correct rejection of distractor items, performance was greatly improved (Lane et al., 2007). The potential contribution of explicit feedback leads to considerations of experimental design beyond the content of the task itself. It is also necessary to consider how the task is administered.

While some amount of novelty makes declarative encoding more likely, the extent of the novelty of these unfamiliar stimuli may adversely impact a participant's ability to later recognize what they have seen when these objects are so unfamiliar that the participant has no previous semantic knowledge to scaffold the newly encoded object (Quent et al., 2021; Miendlarzewska et al., 2016). Similarly, declarative supported rapid encoding of second language vocabulary items was enhanced by prior second language knowledge (Murphy et al., 2021), and children who had limited previous experience with 2D representations of objects are at a disadvantage when cognitive tasks utilize these types of images (Kolling, 2022).

Memory for visual items in paired association tasks might be impacted by participants' experience with 2D images and the complexity of these images (Twum & Parente, 1994; Madan, 2014). Learning that symbolic representations of objects may be used as stand-ins for a real object develops early in childhood (DeLoache, 2000). The amount of exposure to these symbolic or pictorial representations has an impact on the development of the symbolic representation abilities. For example, in rural Tanzania infants aged 15-20 months, who had limited experience with 2D images, could learn the names of novel objects when shown the real object but struggled to learn the names of novel objects when given a picture of the object (Walker et al., 2013). By comparison, American children aged 18 months, who had regular exposure to 2D images, could learn the novel labels from both the real objects and the pictures (Walker et al., 2013). Further, children (aged 6) in Zambia learning patterns were more successful when these patterns were presented with tactile stimuli versus 2D images (Zuilkowski et al., 2016). Potentially, the difficulty of learning from 2D images among individuals with limited experience with these images' memory stems from increased difficulty in encoding unfamiliar complex visual information. For example, the ability to learn items in paired association tasks was reliant on not only a participants' experience with 2D images, but also on the complexity of these images (Twum & Parente, 1994; Madan, 2014). Experience with 2D images can be related to performance on different types of tasks, indeed a statistical learning task among children in rural Côte d'Ivoire found better learning was related to a child's household experience with 2D images (in the form of books and television).

Children, like all humans, are highly susceptible to social cues. Social cues can even override a child's explicit understanding of tasks. For example, when children who had been taught a rule for sorting cards watched an adult sort the cards in a way which violated this rule, those children replicated the errors of the adult instead of adhering to the correct rule (Moriguchi et al., 2007). Feedback during experiments can reduce children's' error and confusion for the task as children aged 3-5 who were given explicit feedback and scaffolding for learning a new rule in a card sorting task performed better than children who were not given explicit feedback (Bohlmann & Fenson, 2005). An experimenter providing feedback to a child during a task, therefore, provides the necessary scaffolding to facilitate memory encoding and reduce participant confusion, but the norms for interactions between adults and children differ cross- culturally and implicit social power structures might mitigate the success of such scaffolding (Perri et al., 2014). Additionally, many experiments designed for children in contexts like the United States are structured as pretend-play games, yet the types of pretend play children engage in is highly culturally dependent and often reflects the child's daily experiences, including how frequently adults engage in pretend play with children, meaning that children with different experiences might have different expectations for both games and playmates (Balton et al., 2019).

Many tests of recognition use a forced choice paradigm which may be insensitive to individual differences in task performance, particularly among children, as forcing a choice may encourage random guessing (Siegelman, et al., 2017; Zinszer et al., 2021), particularly if the participant is confused by the task. Among children and adults, providing the option to respond "I don't know" improved performance on a memory task which required participants to decide which of two tones was longer (Droit-Volet & Izaute, 2009). Others point to the use of forced choice methods as vulnerable to the increasing false recognition among older adults (Faulkner, 2000). How then can children unfamiliar with test taking procedures be expected to perform at their best when experimental methods mimic these? The answer is likely more guidance from experimenters to help children navigate the experiment as qualitative reports from adults with limited experience of test taking procedure point to participant confusion when experimenters do not offer feedback or scaffolding (Aghvinian et al., 2021). The context and experience of a population should matter a great deal to any researcher as these factors may not only affect the participants' abilities to perform well in a testing environment but the content of the measures themselves may also affect outcomes (Freire & Pammer, 2019).

3.1.4 The Current Study

The following study evaluated two common methods of measuring declarative learning, specially adapted for the context of rural Côte d'Ivoire. Both of these measures were translated and adapted so that each item used in each task would be recognizable or familiar for an Ivorian child. The goal was to determine if either of these methods were a reliable measure of declarative learning with little unexplained experimental error. An appropriate test of declarative learning is one which; first, provides a means of accurately capturing declarative learning abilities in children, and, second, is a task which is easily understandable for children with limited experience of formalized testing.

Evaluating these methods for measuring declarative learning is vital for the pursuit of a unified understanding of cognitive development as such an understanding requires that children from all backgrounds and experiences be a part of informing it. Additionally, research related to cognitive development in LMICs often paints a picture of growing up in these contexts in which the cognitive and physical development outcomes influenced by systemic factors, such as poverty and child labor, can be erroneously portrayed as endemic to those contexts. Learning in an LMIC should not be oversimplified or viewed as equal to a learning delay or deficit. Nevertheless, learning across LMICs is varied and complex. Even within HICs, experiential context can impact learning to read. For example, children from lower socioeconomic status families have sometimes been shown to use visuospatial strategies to compensate for poorer phonological awareness (Freire & Pammer, 2019). Mitigating error is vital so that research can both appropriately identify the needs without oversimplifying the differences between growing up in an LMIC versus an HIC. Children growing up in LMICs deserve empirical approaches which are sensitive to cultural and developmental differences.

3.1.5 General Methods

One assessment of declarative learning, The Children's Memory Scale (CMS; Cohen 1997), was designed to measure visual and verbal declarative learning in children ages 8-10 (Samara et al., 2019). The Children's Memory Scale (CMS; Cohen 1997) has been linked to learning supported by the hippocampus (Zureick et al., 2018; Cohen et al., 1990; Willoughby et al., 2014). Similarly, other methods such as the Recognition Memory task, widely used in one form or another among both children and adults, was designed to measure visual recognition of familiar versus unfamiliar objects and has been linked to hippocampal learning (Arthur et al., 2021; Hedenius et al., 2013, Earle et al., 2021; Lum, 2010). Both the CMS and the Recognition Memory task rely to a certain extent on the world knowledge of the child and were designed for children growing up in the US, which likely places children growing up in LMICs at a disadvantage. However, unlike other measures of declarative learning, such as a deferred imitation task, the CMS and the Recognition Memory task are less culturally bound as they do not rely on pretend play interactions between adults and children.

In the first study, children were given the Recognition Memory task. In the second study, children were given the CMS. For both studies, participants were children living and attending school in the Adzopé region of Côte d'Ivoire. The first method of measuring declarative learning, the recognition memory task, was performed among children in the equivalent of 5th grade in 2019. Two years later, in 2021, an independent group of children in the equivalent of the 6th grade were tested using the CMS.

The analyses below evaluated the reliability of the Recognition Memory task and the CMS. Reliability is an indication that a test measures the same construct with very similar results no matter who administers it or who it is administered to (Sobers et al., 2023; Bentler, 2009). One type of reliability is Test-Retest reliability which determines reliability of a measure by examining if a subject behaves similarly across multiple iterations of the same task. Test- retest reliability can be helpful when testing abilities that should not change over time. Test- retest can also be helpful when the observations recorded throughout the test may be affected by variables other than the variable the test is designed to measure, such as time of day or the test administrator. Retesting with the same subjects, however, is not always practical due to timing constraints and the possibility of testing fatigue.

Another type of reliability, internal consistency, indicates whether a subject responds similarly across multiple items within the same test designed to measure the same variable. Internal consistency is a good means of evaluating a measure when there is only data from one time point. If the inter-item correlation is high, this indicates that each item included in a test successfully measures the same latent variable. If the inter-item correlation is low, this indicates that the test does not successfully measure the same latent variable. Low reliability can also indicate the presence and amount of experimental error (Tavakol & Dennick, 2011).

Internal consistency can also be evaluated using the Split-Half method which splits a measure in half and evaluates the correlations between the halves, this analysis is similar to test- retest as it essentially treats the halved test as one iteration. Alternatively, Cronbach's Alpha (Cronbach, 1951), which tests the internal consistency of a measure by examining how the observed variance in test items impacts the correlation between these test items (Drost, 2011). Cronbach's Alpha has an advantage over the split-half method as the split-half method only compares the correlation between two paired test items, while Cronbach's Alpha provides an average of all possible pairings (Yu, 2014). For tasks with binary responses (i.e., 'correct' or 'incorrect') the Kuder-Richardson formula 20 is recommended as, like Cronbach's alpha, it evaluates the average correlation of the entire test (Kumar et al., 2021; Yu, 2014) and the Kuder-Richardson formula 20 is likely equivalent to Cronbach's Alpha (Feldt, 1969).

Validity, unlike reliability, can be a more subjective evaluation of experimental methods. For a test to be valid it must be capable of measuring what it claims to measure. Validity can be determined in multiple ways (Sobers et al., 2023). If a new test is designed to measure a specific construct but is found to be correlated with a test designed to measure a completely different construct then the new test would not demonstrate good discriminant validity. On the other hand, comparing the results of a test to the results of other tests which are designed to measure the same underlying components can indicate good convergent validity. Additionally, rooting the design of a task firmly within previous literature's interpretation of the construct is another possible method of ensuring a new task is valid. Experts regarding the specific component a test intends to measure may verify that the materials included in the test are theoretically well formed. Importantly, while reliability alone is not sufficient to ensure that a task is valid, tasks which are not reliable cannot be considered valid (Cook & Beckman, 2006). For tasks which were developed in, then adapted for, drastically different cultural contexts, poor cultural validity may, therefore, be inferred from the presence of an unusually high amount of unexplained error (as determined by internal consistency) and unusually poor performance (as determined by comparison with the task in other contexts).

3.2 Study 1

This study sought to understand how well the recognition memory task captured the declarative learning abilities of children ages 8-15 attending school in rural Côte d'Ivoire. The recognition memory task is a measurement of visual recognition for real and unreal objects as represented by a black and white line drawing on a screen. Unreal objects in this task are designed to represent things which could reasonably exist but do not, and these objects typically seem mechanical, non-natural (Eals, 1994; Hedenius et al., 2013). The task is a forced choice paradigm as children are only given the option to state either that they have seen the object before or that they have never seen the object before. The adaptation of the recognition memory used in this study was presented on a tablet. After a few training trials, images were displayed at a regular interval with no scaffolding from the experimenter. This was in keeping with the original design of the task as a self-paced task with written instructions. As written instruction would not be effective for non-literate populations, the children performed the remainder of the task after training with only verbal encouragement from the proctor to continue if they appeared to lose interest.

The use of tablets for administering cognitive assessments is widespread even into contexts where experience with such forms of technology is limited (Yuan et al., 2020). Tablets have certain benefits over the use of traditional computers in these contexts, as using external keyboards or a mouse requires that the participant be familiar with the concept of manipulating these seemingly separate physical objects in order to effect changes on a screen. The use of technology-based data collection is widespread, while some do find that performance on tablet- based tasks is similar in both high-tech exposure and low-tech exposure communities (Pitchford & Outhwaite, 2016; Yuan et al., 2020), others advise caution when adapting measures to tablets (Hassler & Ghaderi, 2018). Likely, the potential risk of relying on a tablet-based task in low- tech experience contexts comes from, 1) the inexperience of the participant with digital representations of objects and the associated potential difficulties in encoding those objects (Kolling, 2022), and, 2) from the lack of opportunity for the experimenter to offer feedback on the child's performance. Further potential issues with the recognition memory task in this context may be related to the use of a forced choice design and its measurement of visual recognition alone. It is important, therefore, to understand the applicability of this instrument within the specific context of rural Côte d’Ivoire.

3.2.1 Participants

Fifty children in the equivalent of fifth grade from 6 French monolingual schools in the Adzopé region of Côte d'Ivoire participated in this study. Children (n=51; boys: n=17) ranged in ages from ages 9-15 years. Four children were excluded due to experimental error. The average age of the remaining children was 11.24 years, SD=1.36 (Boys: N=21, M=11.81, SD=1.5; Girls:N=25, M=10.76, SD=1.01). The age at which the children began school was calculated by subtracting the child’s years in each grade (including grade repetitions) from the child’s current age. Average age for a child to begin school was 5.72 years (SD = 1.17) with a range from 4 to 9 years of age (Boys: M=6, SD=1.26; Girls: M=5.48, SD=1.05). Children were included in the study if they were participating in a large literacy study taking place in their schools and were randomly selected with an effort to maintain equal numbers of boys and girls.

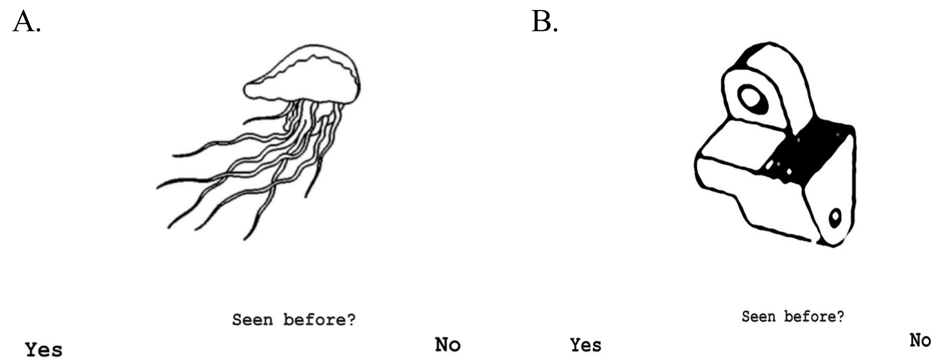
3.2.2 Materials

Declarative learning was measured through an object recognition task originally designed by the Brain and Language Lab at Georgetown University (Hedenius et al., 2013). Children indicated their responses by tapping a corresponding answer on a tablet screen. During this task, children saw a collection of black and white images. Some of these images were drawings of real-life animals or objects, some of these images were representative of non-real objects. The non-real, imaginary, objects were designed to have low nameabilty (Hedenius et al., 2013), that is to say it would be difficult for children to assign a linguistic shortcut instead of relying on spatial/visual memory. These images included only those 'real' line drawings which might be familiar to a child living in a rural area. The original task was translated from English into French by an Ivorian French speaker. Further, this task was adapted from a computer task to a tablet-based task for ease of deployment in rural settings.

During the Encoding phase, when the images were first presented, children were asked to indicate whether the image on the screen was "real" or "imaginary". Children were given 5 practice trials with coaching in order to understand which button indicated which answer. Children saw line drawings of 32 real and 32 non-real (imaginary) objects (Figure 3.1, A and B). Each image appeared for a total of 500 milliseconds.

The recognition phase took place after an interval, during which the participants completed an SRTT (Nissen & Bullemer, 1987; see Experiment 1). During the recognition phase children saw some of the same real and imaginary objects again, this time intermixed with new real and 15 new imaginary objects (seven imaginary and eight real) and asked to indicate if they recognized the image by selecting "Yes" if they had seen before and "No" if they hadn't seen the image before. The recognition phase was also preceded by practice trial with coaching in order to understand which button indicated which answer. These objects were again displayed for a total of 500 milliseconds.

Figure 3.1: A) Example of a Real Object in the Object recognition Task; B) Example of an Imaginary Object in the Object recognition Task (Hedenius et al., 2013, Earle et al., 2021; Lum, 2010).



3.3 Results

3.3.1 Object recognition task

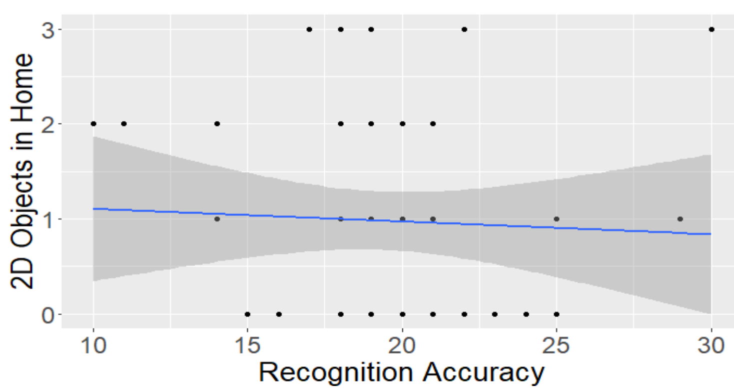
During encoding, the overall accuracy was 56.55% for 38 total trials. For these encoding trials, the accuracy for identifying real images as real was 62.47%. The accuracy for identifying imaginary objects as imaginary was 50.69%. A two-proportions Z-test found that the accuracy during encoding for real and imaginary images were significantly different from one another ($z= 24.23$, $p<.001$), such that the proportions of accurate imaginary trials was less than the proportion of accurate real trials. During recognition, the overall accuracy was 51.37% for 38 total trials. For these recognition trials, the accuracy for identifying real images that were seen before and rejecting real images that had not been seen before was 51.33%. The accuracy for identifying imaginary images that were seen before and rejecting imaginary images that had not been seen before was 50.87%. A two-proportions Z-test found that the accuracy during recognition for real and imaginary images were not significantly different from one another ($p=1$).

3.3.2 Item Analysis

Of the 38 images used in the encoding phase of the task, fewer than half of the children correctly identified 13 of the images. Of these 13 images, 9 were imaginary and 4 were real. Of the 38 images used in the recognition phase, fewer than half of the children correctly identified 17 of the images. Of these 17 images, 10 were imaginary and 7 were real. Two of the images with low accuracy in the recognition phase were images children had seen before and both of these images were imaginary.

Further analysis examined the possible relation between experience with 2D images and performance in the object recognition task. Some of the children had access in their homes to objects which could allow them to experience 2D images (in the form of television, child's books, or other reading material). Among the children in this study, the presence of these items in the home was uncommon (Television: 15.75%; Child's Book: 10.23%; Other reading material: 9.45%). For children in the recognition phase, the ability for children to distinguish between images that they had seen before and images which were new was compared to the presence of these objects. There was no significant correlation between 2D images in the home and performance on the object recognition task (see figure 3.2).

Figure 3.2: Scatterplot for the relation between Recognition accuracy and 2D objects in the child's home.

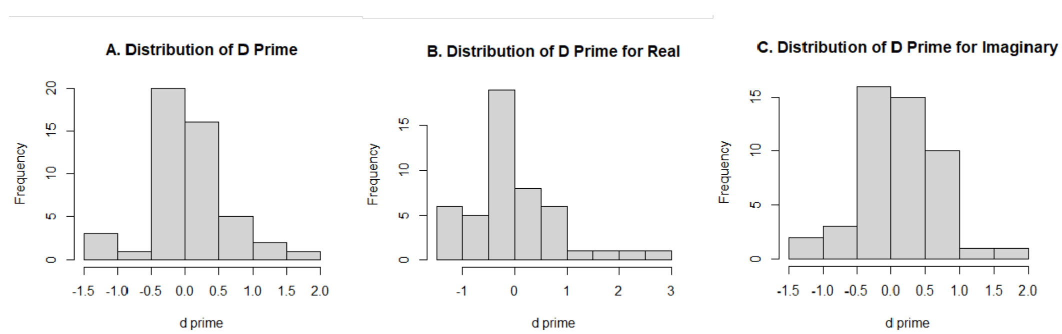


3.3.3 Subject Sensitivity

D' scores were calculated for each subject to examine their sensitivity in the recognition phase of the object recognition task. D' of a subject's ability to correctly identify a target when it is present and not to say there is a target when there isn't one (Abdi, 2007). A d' of zero indicates no discrimination between a target and a false alarm and may therefore indicate answer bias, such that a subject responds "yes" to every trial regardless of what they see. A negative d' might indicate that a subject is reliably saying "yes" to an image when the answer is "no" they had not seen it before, which is likely a sign of poor task compliance. For the recognition phase of the object recognition task, the average d' was 0.1 (SD=0.55), indicating sensitivity which was just above chance. However, the d' scores ranged from -1.05 to 1.60. Many children, therefore, were at chance or below chance in their discrimination and some reliably indicated that an image had been seen before when it had not (see 3.3A). Comparing real and imaginary images in the recognition phase, the mean d' for real was -0.06 (SD=0.84, range=-1.36-2.69; see Figure 3.3B) and for imaginary it was 0.12 (SD=0.57; range=-1.12-8.86; see Figure 3.3C). A t-test, however, did not find that the scores for real and imaginary significantly differed (p=.24).

A secondary d' analysis examined if the sensitivity measures might be higher if images which demonstrated low accuracy in the encoding phase were omitted in the recognition phase. The d' without these low accuracy images was higher but only slightly (M=0.19, SD=0.61, range=-1.22-1.61). A t-test indicated that this d' was not significantly different from the d' including those low accuracy images (p=0.49).

Figure 3.3: A. Histogram of total d'; B. Histogram of real d'; C. Histogram of imaginary d'



3.3.4 Reliability

Forty-eight children took a 76 item Object Recognition task including the encoding and recognition conditions. To examine internal consistency the Kuder-Richardson formula 20 (equivalent to Cronbach's Alpha but suited for dichotomous data) indicates how well items correlate with each other. The stronger the correlation the more likely it is that items are measuring the same construct. Weaker correlation indicates the presence of experimental error and the potential for confounding variables interfering with the measure of the target variable, in this case declarative learning. The Kuder-Richardson reliability was 0.82 which is considered to be good. The Object Recognition task, therefore, had an acceptable internal consistency. However, looking at the encoding and recognition conditions separately, the encoding phase (38 items) the Kuder-Richardson reliability was 0.77 which is considered to be acceptable but the recognition phase (38 items) had a Kuder-Richardson reliability of 0.69 which is considered to be questionable. Further, looking separately at the performance on real and imaginary items, both reached acceptable internal consistency (real; KR20=0.77, imaginary; KR20=0.76). Therefore, while the test as a whole seemed to have good internal consistency, differences in encoding and recognition indicate a potential for experimental error in the recognition phase. It should also be noted that good internal consistency does not necessarily mean that a task was successful, indeed a 'yes' bias, or a tendency to say 'yes' in every trial, would still present a good internal consistency.

3.4 Discussion: Study 1

As the recognition memory task has been measured among participants growing up in different contexts and these iterations of the test have demonstrated high internal consistency (Arthur et al., 2021). It has also been used among children in Sweden comparing typically developing children and children with dyslexia (Hedenius et al., 2013). While Hedenius and colleagues (2013) do not report reliability, they do find a difference in encoding real and imaginary images such that there was better encoding for real images and this difference was present in both groups. Among typically developing children in Sweden d’ was reported as 2.71 for real images and 1.15 for imaginary (Hedenius et al., 2013). Further, among children in Hungary, typically developing and with specific language impairment, the same encoding advantage for real images was reported (Lukács et al., 2017). Among typically developing children in Hungary d’ was reported as 2.18 for real images and 1.12 for imaginary (Lukács et al., 2017). A longitudinal study of children in the United States given the object recognition task each year from first to fourth grade also found a difference between real and imaginary objects and, while they found that performance on the object recognition task improved with age, however they did not find that the advantage for real images changed with age (Earle et al., 2021). Among children in the United States the reliability of the object recognition task (as Cronbach’s α) was reported to be 0.84 for first grade, 0.83 for second grade, 0.81 for third grade, and 0.79 for fourth grade (Earle et al., 2021).

Compared to the previous uses of the object recognition task as reported above, the performance among this group of children in rural Côte d’Ivoire was low. In particular, while many previous studies report an advantage for real images over imaginary, the results above point towards no real image advantage. During recognition, there was no significant difference between real and imaginary images. Instead, the d’ score for real images indicates a potential yes bias for real images. The identification of a real object may have been confused for the recognition of an image not seen before. During encoding real images were more accurately identified than imaginary images. It is possible that even if the child did not recognize the image itself they were able to tell the difference between nameable versus unnamable objects. Unnamable objects are also quite difficult to succinctly describe while the nameable objects, even if they were not familiar, possessed some describable characteristics. Again, while children were not able to recognize real objects, they could distinguish between real and imaginary images.

Poorer than expected performance in the object recognition task may be related to task compliance. Some anecdotal reports during data collection indicated that children were sometimes confused by the task. Additionally, anecdotal reports suggested that some children were hesitant to touch the tablet and needed to be encouraged, unsurprising as very few children in rural Côte d'Ivoire would have any experience with touch screens. Touching which answer is correct would not be a familiar task and relies on children understanding the mapping between 'the answer is yes' and 'touching this *yes* on the screen means my answer is yes'. This mapping requires children to create dual representations of the symbol 'yes' and the answer 'yes' (DeLoache, 2000), a task which may be unexpectedly challenging when a child has little experience with these dual representations. Additionally, if the child is not able to read the word 'yes' on the screen (presented in French), as many children in Côte d'Ivoire would not be able to, then the child must keep in mind what they have been told at the beginning of the task, that these letters mean yes.

Poor performance among a single sample and anecdotal reports may not be enough to determine if the object recognition task is culturally or ecologically valid. The low reliability of the recognition phase, however, provides evidence of unexpected experimental error which was not observed in previous uses of the task in different contexts. Whether this experimental error is related to participants' socio-cultural expectations (cultural validity) may not be definitively established, the absence of the previously observed real item advantage in this population points toward children's unfamiliarity with task items. If these real objects were identified by children and linked to a preexistent concept in semantic memory then the real item advantage would likely have been present. Despite selecting real objects that Ivorian children may have had previous experience with, they were not able to easily encode these 2D objects. In the encoding phase, children could reliably distinguish between real and imaginary objects but could not recognize these objects after a delay, suggesting that the use of 2D images presented on a screen may be related to difficulties with encoding. Indeed, few children who participated in this study had a television or books in their home. The cognitive abilities that the majority of Ivorian children use in daily life, therefore, was not well represented by this task. However, there was no observable link between a child's previous experience with 2D images and their performance on the object recognition task.

3.5 Study 2

Measures of abilities which are rooted in world knowledge, such as declarative learning, are likely not appropriate in all contexts, however, very little research has actually evaluated this assertion. Previous means for gathering measures of declarative learning among children growing up in Côte d'Ivoire may have demonstrated that data collected from methods relying on abstract tasks and forced choice may be noisy and potentially unreliable (See Study 1). Anecdotal reports from experimenters involved in Study 1 present concerns about the use of the recognition memory task as children were slow to respond and often seemed confused by the task. The use of digitally presented line drawings used in the recognition memory task may be difficult for children with limited experience with these types of images and therefore may not be used to think of 2D images as representative of real, 3D objects. Additionally, the distractor task during the encoding phase of the experiment requires that the child make a judgment of whether these figures are real or imaginary, and all 2D images are in some way not real. To these children, this task may have been unnecessarily confusing and this confusion may have been detrimental to the child's encoding. Children may benefit from the use of more real-world, physical measures of declarative learning compared to virtually presented means of data collection. Further, the recognition memory task gives limited opportunities for experimenters to scaffold the child as they do the task. Children receive feedback during training trials but must concentrate silently on the images for the remainder of the task with no assistance from the experimenter. Finally, the use of a forced choice paradigm may have been insensitive to children's actual declarative learning abilities, as children could choose at random when confused.

In the following study a well-established assessment of declarative learning (Children's Memory Scale; Cohen, 1997) was adapted and used to ascertain if more real-world measures which reduce the reliance on abstract reasoning and more scaffolding from experimenters can provide a more context-appropriate means of data collection in contexts like rural Côte d'Ivoire. Unlike the recognition memory task (see Study 1), the Child's Memory Scale (CMS; Cohen, 1997) consists of tasks, which evaluate two components of declarative learning, verbal and visual (Bremner et al., 2004). Additionally, both recall and recognition tasks are included. The measures of verbal declarative learning included in the CMS include a word list memorization task and a task of paired association (Word Pairs) in which children learn to recall a word based on an unrelated pair (see further description below). Including the verbal component, which was not a part of the recognition memory task, allows for a more nuanced measure of declarative learning abilities which may be more relevant for answering questions regarding how declarative learning might contribute to reading in a certain population, particularly as memory for visual- verbal associations supported by the declarative system are linked to the phoneme-to-grapheme mapping skills essential to early reading development (Hulme et al., 2007; Liu & Chung, 2021; Wang et al., 2017). The measures of visual declarative learning included a Dot Location task in which children recreate a matrix of dots by physically manipulating chips, placing them in certain locations on a grid. The physical manipulation of the chips likely would not make the same demands on abstract reasoning as a 2D representation. The Dot Location task additionally adds to the nuance of the greater declarative learning measure by incorporating spatial declarative learning into the task.

The original CMS was written in English, and included three further tasks, listening story comprehension, sequence learning, and number reordering, which were omitted in order to shorten testing time. During the story comprehension task, a child listens to a story and then repeats the story back to the experimenter. The child is scored based on the major thematic elements they can recall. The stories task was omitted as directly translating the stories from the CMS into French might change the length of the story, saliency of the themes, and frequency of the words. As the focus of this experiment was exclusively on how well this assessment captured declarative learning in this context, additional tasks from the battery which measured other, related constructs were omitted. Specifically, the number reordering and sequence learning tasks were omitted as these tasks did not contribute to the overall declarative learning score, but measured attention.

In this adaptation of the CMS, instructions and test items were directly translated into French by a native French speaker and then this translation was confirmed by a native speaker of Ivorian French. The same speaker of Ivorian French also confirmed the likelihood that a child in rural Côte d'Ivoire would be familiar with every item from the verbal subtests. In only one instance the word 'pencil' in the word pairs task, the direct translation of which would be 'crayon,' was replaced with 'stylo,' which translates to pen as this was a term with which the children would be more familiar. Finally, a measure of visual declarative learning, the Faces task (see description below) originally contained images of faces which the subject would need to recall later by recognizing them among a set of new faces. In the original version of the CMS, these task items were primarily images of white individuals and would not have reflected the people children in rural Côte d'Ivoire would encounter on a daily basis. With only a few exceptions (i.e., images from the CMS which depicted Black individuals) test items were replaced by images from other databases; Face Research Lab (DeBruine & Jones, 2017), Chicago Face Database (Ma et al., 2015), FEI Face Database (do Amaral et al., 2016), American Multiracial Faces Database (Chen et al., 2021), Developmental Emotional Faces Stimulus Set (Meuwissen et al., 2017), Face Database (Minear &

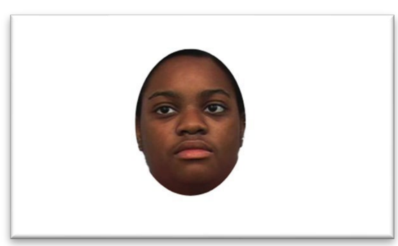
Park, 2004), NIMH Child Emotional Faces Picture Set (Egger et al., 2011), and the Face Place Database (Righi et al., 2012; see figure 3.4 A and B). Each image was selected to match each individual test item as closely as possible in terms of age and gender (see figure 3.4).

The analysis below includes an examination of the results from the adapted CMS, evaluating how children fared on each individual task. The components of the declarative learning included in the CMS (i.e., visual and verbal) were compared through a paired-sample t- test. Finally, further analysis will evaluate this measure's internal consistency, as in Study 1, using Cronbach's Alpha (Cronbach, 1951), which tests the inter-item correlation of test items. If the inter-item correlation is high, this indicates that the items of the test successfully measure the same latent variable. If the inter-item correlation is low, this indicates that the test does not successfully measure the same latent variable. Low Cronbach's Alpha can also indicate the presence and amount of experimental error (Tavakol & Dennick, 2011). As the internal consistency of the CMS has been measured and validated among participants growing up in contexts like the United States, inferences of poor cultural validity may be made if experimental error is higher than observed in other contexts. It is, of course, possible that error may be attributed to many different factors, but it is one potential and likely explanation. If this adapted CMS was found to have relatively low experimental error then it is likely that the measure is also culturally valid.

Figure 3.4: A) Example of a face from the original Child's Memory Scale (Cohen, 1997). B) Example of a face from Face Database (Minear & Park, 2004). Used with permission.

A.

B.



3.5.1 Participants

One hundred and twenty-seven children in the equivalent of sixth grade from 15 French monolingual schools in the Adzopé region of Côte d'Ivoire participated in this study. Children ranged in ages from ages 9-15 years (M=10.52, SD=1.44). Of these children 63 were girls (M=10.41 SD=1.55) and 62 were boys (M=10.63, SD=1.32).

3.6 Materials

3.6.1 Children's Memory Scale:

Dot Location is a measure of declarative, non-verbal spatial memory. Children are shown a picture of a 4X4 grid with a pattern of 8 dots located in the squares for 5 seconds. The picture is removed and the child is asked to recreate the pattern they just saw on an empty grid, using plastic tokens. The experimenter provides feedback on the correct location of misplaced tokens. Then the experimenter clears the board and asks the child to recreate the pattern again. The child is then shown a distractor pattern of different color dots in different locations on the grid. The child is asked to recreate this distractor pattern. The experimenter provides feedback on misplaced tokens, then clears the board and asks the child to recreate the distractor pattern again. After the second time producing the distractor pattern, without representing the picture of the first pattern, children were then asked to reproduce the initial pattern once again; initial recall. After a delay of about 20 minutes the children are again asked to reproduce the initial pattern; delayed recall. A point is awarded for each dot in the correct location for the initial recall score and the delayed recall score.

During **Word Pairs** children passively listen to a list of 14-word pairs such as 'rice/chair'. After a pause of 5 seconds children are asked to recall half of the list by being prompted by the target word's pair: "which word goes with rice?" This is repeated twice with the pairs remaining the same but their order in the list changing randomly. Children were given feedback in every trial and, when necessary, provided with the correct answer. The three total repetitions of the list of word pairs was followed by immediate recall during which children were then asked to recall the word pair for each word but were given no feedback.

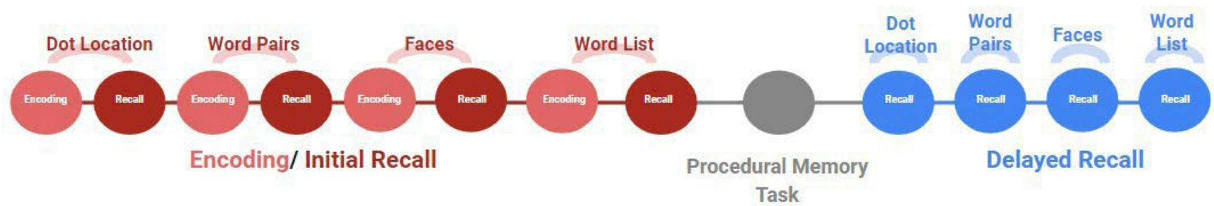
During **Faces**, children watched an 8 second video in which they saw 16 young and old faces of individuals. Each face was on the screen for only two seconds. Children were then given an immediate recall task in which they looked at 48 faces in a slide show, including 50% new faces and 50% from the video. The children were asked if they remember seeing each face before.

During **Word List,** children learn a list of 14 unrelated words over four learning trials. The child's goal during this task is to recall as many words as possible in any order from a list of 14 unrelated words read out by the experimenter. The experimenter reads the list slowly to the child then asks the child to repeat back all of the words. If the child misses a word the experimenter reminds the child of the missed words. This process repeats four times. The experimenter reads the child a new list of ten unrelated words and has the child repeat that list back. The child hears and then repeats the second list a total of four times. The child is then asked to recall the original list; immediate recall. After a delay of about 20 minutes the child is again asked to remember the first list of words; delayed recall. The number of words remembered across the first five trials are added to the child's learning Score. Additionally, the number of words recalled at the immediate recall and delayed recall provide the child's immediate and delayed memory scores.

After children completed all of their initial recall tasks they completed a measure of procedural learning, the SRTT (see Chapter 2 Study 1), which meant that the child remained with the experimenter during this delay. Additionally, because the task consistently takes around 20 minutes to complete, it allowed the experimenter to easily ensure that each child had roughly the same delay between the initial and delayed measures of the CMS. Once the SRTT was complete, children completed a delayed recall task for Dot Location, Word Pairs, and Word

List. There were also delayed recognition tasks for Word Pairs and Faces during which the children answered whether or not they remember seeing or hearing certain items before (see figure 3.5).

Figure 3.5: Timeline of CMS subtests



3.7 Results

The means and standard deviations for the testing conditions of each subtest are reported below in table 3.1. For the Dot Location task, the average child's accuracy across both training and testing was 58.38% (SD=7.46, range=6.25%-73.44%). For the Word Pair task, the average child's accuracy across both training and testing was 25.49% (SD=11.03% range=1.45%- 62.32%). For the Faces task the average child's accuracy across both initial recall and delayed recall was 67.81% (SD=10.51% range=44.79%-91.67%). Finally, For the Word List task the average child's accuracy across both training and testing was 35.19% (SD=9.67%) the accuracy of this task varied widely (range=15.31%-60.20%). A t-test demonstrated that the combined verbal accuracy scores were significantly different from the combined visual accuracy scores ($t(233.8) = -33.07$, $p < .001$).

Table 3.1: Adapted CMS Raw Scores

Task		M	SD	Range
Dot Location (0-8)	Initial	5.06	1.12	2-7
	Delayed	5.39	1.42	0-8
Word Pair (0-14)	Initial	3.73	1.94	0-10
	Delayed	2.86	1.85	0-11
Faces (0-48)	Initial	32.59	5.61	1-45
	Delayed	32.51	5.93	18-46
Word List (0-14)	Initial	5.30	2.13	0-10
	Delayed	4.70	2.24	0-11

3.7.1 Comparing Subtests

A component of construct validity is whether all items within a test are measuring the same construct. For the current study's adaption of the CMS, correlations between the subtests demonstrate the likelihood of each subtest measuring the same construct. In the initial phase, the subtests for the two visual measures (Dot Location and Faces) were correlated as were the subtests for the two verbal measures (Word List and Word Pairs; see table 3.2). In the delayed phase, the subtests for the two verbal measures were correlated but the subtests for the two visual measures were no longer correlated (see table 3.3). Instead the Dot Location task was correlated with the Word List task. Potentially, as both the Dot Location and Word List were particularly difficult tasks, they are correlated because children with higher scores were more generally skilled in cognitive abilities which support testing and task compliance such as attention, working memory, or task switching. Additionally, children with greater French abilities might benefit both in the verbal task (i.e., Word List) and with the visual task that required more instructions from experimenter (i.e., Dot Location).

Table 3.2: Initial Correlations

	1	**2**	**3**
1.Dot Location			
2.Word List	0.09		
3.Faces	.24**	0.13	
4.Word Pairs	0.09	.39***	0.11

Pearson correlations without corrections

Table 3.3: Delayed Correlations

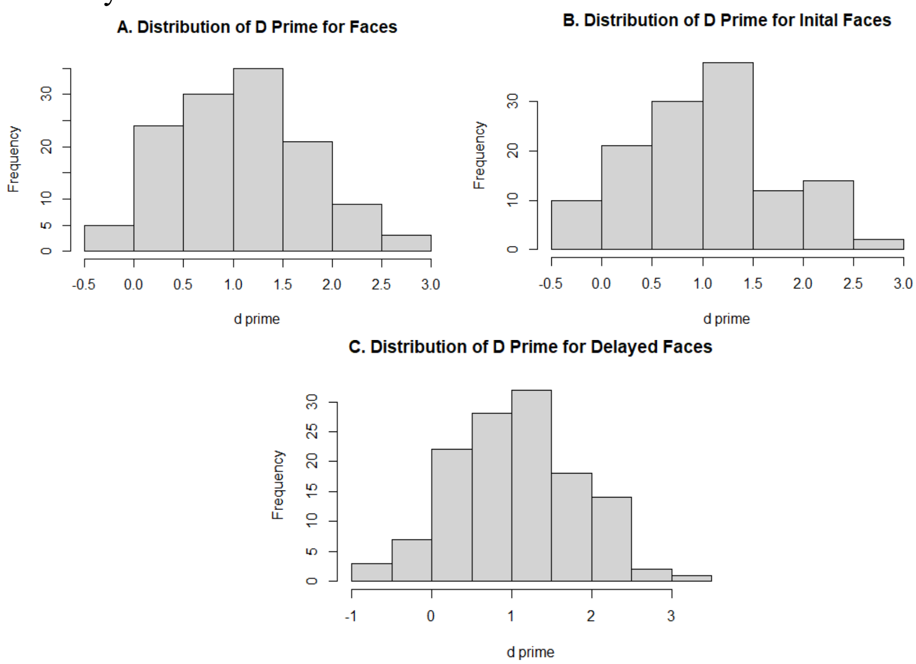
	1	**2**	**3**
1.Dot Location			
2.Word List	.26**		
3.Faces	.014	.06	
4.Word Pairs	0.10	.31***	0.17

Pearson correlations without corrections

3.7.2 Subject Sensitivity

D' scores were calculated for each subject to examine their sensitivity in the Faces. For the faces task the average d' was 1.1 (SD=0.68) above chance sensitivity, the range of d' scores ranged from -0.27 - 2.80. Many children, therefore, were at chance or above chance in their discrimination reliably indicating that they recognized faces they had seen before and rejected faces they had not seen before (see 3.6A). For the initial recall of the faces task the average d' was 1.06 (SD=0.72) indicating above chance sensitivity the range of d' scores ranged from -0.44 - 2.84 (see 3.6B). For the delayed recall of the faces task the average d' was 1.07 (SD=0.67) indicating above chance sensitivity, the range of d' scores ranged from -0.27 - 2.80 (see 3.6C).

Figure 3.6: A. Histogram of total Faces d'; B. Histogram of initial faces d'; C. Histogram of delayed Faces d'



3.7.3 Reliability

One hundred and twenty-seven children took a 327-item adaptation of the Children's Memory Scale including the four subtests of dot location, word pairs, faces, and word list. Eight children were removed for the internal consistency analysis due to missing data. All of the subtasks together had a Cronbach's Alpha of $\alpha = 0.91$ which is considered to be good. The adaptation of the Children's Memory Scale, therefore, had a good internal consistency. Of the four subtests, word pairs and word list had good internal consistency (items=69, $\alpha = 0.86$) word list (items=98, α = 0.81); faces had excellent internal consistency (items=96, α = 0.82); and dot location had unacceptable internal consistency (items=64, α =0.40).

3.7.4 Adapted CMS compared to Original CMS

The CMS is a standardized assessment the reliability of which was extensively tested across ages and groups within the United States (Cohen, 1997). In order to test how this adaption compared to the original version of the CMS the reliability of each subtest was tested with split- half correlations with Spearman-Brown corrections as these were the reliability scores originally reported by Cohen (1997). The Spearman-Brown correction predicts the full test reliability of a split-half correlation (Eisinga et al., 2013). The reliability was measured across training trails for Dot Location, Word Pairs, and Word List, the initial recall for Faces (as this subtest had no training data). The reliability of Dot Location in the adapted CMS was again poor particularly compared to the original CMS (see table 3.4). The reliability of Word Pairs, Word List, and Faces was good and comparable to the original CMS (see table 3.4). In fact, the reliability of the Faces task was higher than the original CMS.

Table 3.4: Spearman-Brown correction of split-half correlations for training data from Dot Location, Word Pairs, and Word List, and initial recall for Faces subtask. Results from the current adaptations are compared to reported reliability in relevant age groups from Cohen (1997).

Subtest	Current Study Ages 9-15	CMS Age 9	CMS Age 10	CMS Age 11	CMS Age 12	CMS Age 13-14	CMS Age 15-16
Dot Location	.34	.61	.75	.65	.76	.81	.68
Word Pairs	.83	.87	.92	.90	.93	.94	.91
Faces	.83	.69	.73	.72	.68	.64	.74
Word List	.75	.86	.89	.85	.82	.82	.84

3.8 Discussion Study 2

The above adaption of the CMS was designed to measure declarative learning among children in rural Côte d'Ivoire in a culturally and ecologically valid way. In pursuit of this subtasks were selected from the original assessment which; 1. Minimized adult-child interaction. 2. Incorporated both recall and recognition and verbal and visual aspects of declarative learning. And 3. Did not rely on children's ability to encode 2D images. The tasks included were both visual and verbal. In the initial phase of the adapted CMS the visual tests were positively correlated with one another as were the verbal subtests indicating that, in the initial phase at least, these two aspects of memory were represented with good construct validity. In the delayed phase the verbal subtests were correlated but the visual subtests were not. Instead, Dot Location was correlated with the Word List subtest. Potentially, as both the Dot Location and Word List had lower accuracy the correlation may be related to poorer test performance more generally. Another potential reason for the correlation between Dot Location and Word List, similar to the first, is that poorer French speakers may have struggled with both recalling words and with following instructions during the Dot Location task.

Previously the CMS has been used to examine memory differences among children with epilepsy in the United States, ages 6-16, found that typically developing children performed similarly on the Dot Location and Faces subtests (Borden et al., 2006). Children in the United Kingdom, aged 7-8, also demonstrated high performance on the Dot Location subtest (88% total accuracy in learning) and they also demonstrated a high internal consistency for this task (.76 Split-half reliability; West et al., 2018). Across these previous uses of the CMS subtests in high- income-countries high performance were reported suggesting that any poor performance observed in the study is related to the subtests fit within the specific cultural context.

Overall, the accuracy of the visual tests were higher than the verbal test, potentially this signifies lower French vocabulary as previous chapters have found low French vocabulary scores among children in rural Côte d'Ivoire (see Chapter 2). Visual scores are less dependent on French knowledge however children still need to know enough French to understand task instructions. Of the visual tasks, the Dot Location subtest had lower accuracy and very low reliability. Potentially, the complexity of the task made it difficult for children to remember the locations on the grid. Comparatively, the Faces subtest had higher accuracy and better internal consistency. It is likely that the Faces subtest was so successful in this sample because of the Ecological validity of the task. The ability to recognize individuals would be something children used on a daily basis. Additionally, while the Faces subtest is a test of visual recognition the Dot Location subtest tests visuospatial memory. It is possible that the Dot Location test was not close enough to real life skills for Ivorian children to master. Indeed, among low-SES children aged 10-12 growing up in rural United States demonstrated poorer visuospatial working memory relative to verbal working memory, low-SES children growing up in urban areas did not demonstrate this difference (Tine, 2014). Tine (2014) argues that poorer visuospatial working memory for children growing up poor in rural areas is related to reduced exposure to visual stimulation. Others have also noted differences in visuospatial processing as measured through certain IQ tests are culturally biased as individuals, particularly those from LMICs demonstrate poorer performance in tasks that require manipulating abstract shapes (Gonthier, 2022). In light of this, the Dot Location is likely not a culturally valid task.

3.9 General Discussion

3.9.1 Comparing the Recognition Memory Task and the CMS

Both the CMS and the recognition memory tasks have been widely used to measure declarative learning in children. How capable these measures are at capturing declarative learning outside the laboratory and outside the contexts of HICs, however, remains to be seen. The goal of study 1 and 2 was to determine if either of these methods was capable of reliably measuring declarative learning, that is measuring the same latent variable of declarative learning, with little unexplained experimental error. In order for an assessment to meet these two criteria it must; 1) measure multiple aspects of declarative learning in multiple ways, 2) use task items which are simple enough to be memorable for children with limited experience of 2D images presented on a screen, and, 3) provide children with the necessary guidance and scaffolding to understand the task they are given. In light of these criteria, it was likely that the CMS would most accurately and appropriately measure declarative learning in rural Côte d'Ivoire. Indeed, for the CMS cohort, children's accuracy as well as measures of sensitivity and internal reliability, were superior to the Object Recognition cohort in every respect.

Given the poor results from the Object Recognition cohort alone, one might ask why it is that children growing up in rural Côte d'Ivoire perform differently compared to children of similar ages growing up in places like the United States? However, given the performance of the adapted CMS cohort, particularly regarding the Faces subtest it is clear that children in rural Côte d'Ivoire can perform just as well as children in previously studied contexts, provided they are given culturally and ecologically valid tasks. Reliable measures of declarative learning are especially important when declarative and procedural learning are proposed to play unique roles in learning in childhood and throughout later life. It is vital to acknowledge how measurements of psychological or cognitive phenomena may be impacted by the cultural context of data collection.

Chapter 4

DO ADOLESENT EMERGENT READERS RELY DIFFERENTLY ON DECLARATIVE AND PROCEDURAL LEARNING?

Reading is a complex skill that relies on multiple cognitive and linguistic abilities. Including the cognitive ability which underlies all of our learning abilities, and memory. According to the Declarative/Procedural Model (DPM; Ullman, 2013), two memory systems (i.e., procedural and declarative learning) contribute to, and support, different aspects of language and language-related skills, such as reading. Under the DPM, procedural learning supports the learning of linguistic structure (e.g. phonology, aspects of syntax), while declarative learning supports the arbitrary aspects of language such as mapping of form and meaning (e.g. lexicon). The procedural and declarative systems have distinct developmental trajectories: procedural learning becomes adult-like around early adolescents (Lee et al., 2020, Finn et al., 2016), while declarative learning matures throughout adolescence (e.g., DiGiulio et al., 1994). There is evidence that the earlier maturation of procedural learning may lead to a more prominent role of procedural learning for younger children acquiring new skills (Van der Linden, M., & Roulet-Perez, E. 2016; Quam et al., 2018). The DPM posits that as declarative learning matures, declarative learning abilities overlap, and compete, with procedural learning abilities. Potentially, as children age, learning (including emergent reading) becomes less dependent on procedural learning while the importance of declarative learning to emergent learning increases. The increasing maturation of declarative learning for adolescent emergent readers may offer insight into the nature of emergent reading among an often-overlooked population, children learning to read for the first time in late childhood or adolescence– critically, at a time when declarative learning is more mature.

Many children around the world fail to learn to read. In particular, children growing up in low resource contexts in low- and -middle-income countries

(LMICs), even after attending six years of primary school, may complete primary school but will still be unable to decode a single word. Despite this crisis for global literacy, the specific challenges of emergent reading in LMICs receive little attention from reading research. Typically, reading research takes place in places like the US where children enter school for the first time, and therefore start learning to read, around age five and receive consistent support and years of instruction as their reading skills develop. For many children, however, the experience with reading instruction can be very different. Children in low- and middle-income countries may enter school later in childhood and attend school inconsistently, therefore, their first exposure to, and subsequent experience with, reading is vastly different than children attending school in the US. It is vital to understand emergent reading among children who are learning to read later in childhood as research suggests that adolescent emergent readers often have poorer reading outcomes compared to younger emergent readers (Jasińska et al., 2022; Hannon et al., *under review*). In part, the increased difficulties in acquiring reading with age may point to changing cognitive development (including memory development), which may qualitatively change how older children learn.

4.1 The DPM on Reading

Procedural learning supports the ability to learn new phonological patterns or reproduce such patterns with automaticity. Procedural learning supports reading abilities through phonological decoding, this early decoding ability relies on a child's knowledge of language, including phonological awareness, that is, the understanding and ability to manipulate sound units of language (Bradley & Bryant, 1983). The phonological knowledge developed through procedural learning allows a reader to map phonemes (e.g., 'θ'or 'ð') to the grapheme which represents that phoneme (e.g., letters, or letter combinations such as 'th'; Franceschin et al., 2021, Lum, Ullman, & Conti-Ramsden, 2013; Nicolson & Fawcett, 2007; Snowling & Griffiths, 2004). For example, procedural learning contributed to adults' ability to learn novel phoneme-to- grapheme mappings and maintain stable representations of these mappings even after a delay (Bitan & Booth, 2012). Among typically reading adults, better procedural learning of a manual dexterity task was linked to better phonological decoding (Franceschin et al., 2021). Among children, a longitudinal study of children through their first year of reading instruction found that in the very earliest stages of reading acquisition children depend on sequence learning abilities within short-term memory to support decoding, presumably because they must keep each successive relation between phoneme-to-grapheme in mind while building towards the completed word (Nithart et al., 2011). Further this short-term memory for sequences contributes most to early reading but is replaced in importance by the knowledge of orthographic forms in long-term memory as reading skills mature and children become able to recognize words they have seen before (Nithart et al., 2011; Ordonez Magro et al., 2020). Even in later stages of emergent reading, procedural learning contributes to phonological processing and to orthographic processing for unfamiliar words that require decoding (Carreteiro & Figueira, 2017).

Declarative learning supports rote memorization of written symbols and their associated sounds or meanings (Earle et al., 2020), and vocabulary. As this word knowledge increases the reader can increasingly rely on the meanings of surrounding words to interpret unfamiliar words. Consequently, increasing world knowledge, as supported by increasing declarative learning, coincides with an increasing importance of vocabulary for reading (Snow, 2002; Tannenbaum, Torgesen & Wagner, 2006). The benefits of declarative support for vocabulary and reading is not uniform for every emergent reader, however. Among children reading in a second language, declarative learning contributed to the ability to learn and retain new vocabulary from reading, but this contribution was only evident among children with better preexisting knowledge of their second language vocabulary (Murphy et al., 2021). Indicating that declarative learning, the system of semantic knowledge, increases as greater world knowledge scaffolds further semantic encoding.

4.1.1 Skill Learning

In general, many skills may start off with declarative support and change to procedural support as they progress (Anderson, 1987; Ullman & Lovelett, 2018; Willingham, Nissen, & Bullemer, 1989). Increasing proceduralization is vital for a learner to become a more specialized skill user because it increases the automaticity with which a learner can apply their new skill. For example, adults learning to classify cards depicting weather events initially relied more on neural regions associated with declarative learning (i.e. the medial temporal lobe) but, as they became more skilled, procedurally related neural regions (i.e., the basal ganglia) began to demonstrate greater activation (Poldrack et al., 2001). Additionally, adults learning an artificial second language with a semantically controlled morphosyntactic rule first learned this rule explicitly before developing a more implicit ability to apply the rule (Ferman et al., 2009). What was previously supported by declarative learning becomes more proceduralized as learners become more able to make correct predictions when performing the learned skill (see Chapter 1 for further discussion; Anderson, 1987; Ullman & Lovelett, 2018; Willingham, Nissen, & Bullemer, 1989; Morgan-Short et al., 2012).

In reading, the memorization of the grapheme-to-phoneme mapping which allows the reader to decode words is initially supported by declarative learning but becomes proceduralized as skills increase allowing a skilled decoder to read unfamiliar words with little effort. One study of the very earliest stages of reading development for first graders in the US showed that the initial stages of reading development was supported by declarative learning, with procedural learning becoming more important for reading among second graders (Earle et al., 2020) suggesting that when first learning to decode, readers must first pass through the declarative-memorization stage before progressing to the procedural- decoding stage during which these mapping can become automatic. After decoding becomes more skilled, a second declarative stage supports a reader's ability to recognize the whole orthographic sequence.

Later, declarative learning supports the reader's ability to recognize familiar words. Among older emergent readers, however, this progression is less clear.

While there is minimal evidence from older emergent readers, the research that exists demonstrates that older learners tend to first rely on declarative learning to explicitly memorize their new skill before that skill is proceduralized for the learner to be able to perform it with automaticity. Emergent readers whose declarative learning is more mature (i.e., those in later adolescence) likely rely more heavily on declarative learning for any type of emergent skill learning. Additionally, as individuals age, declarative learning begins to overlap with previously procedural learning. Potentially, older emergent learners, whose declarative learning is in competition with procedural learning, do not progress beyond the initial declarative stage of reading. Declarative-supported reading, however, requires greater and more effortful cognitive engagement (Bitan & Karni, 2004). Consequently, the declarative competition to support emergent reading in older readers may impede their ability to become a skilled reader.

4.1.2 Memory and Learning with Age

The DPM posits that the memory systems which support emergent language learning changes from childhood to adulthood (Ullman et al 1997; Morgan-Short et al 2010). Procedural learning, which matures as a child enters adolescence, contributes to early skill learning in children but becomes less influential for skill learning among adults. Declarative learning, which continues to mature into adulthood, contributes to early skill learning in children but becomes more influential for skill learning among adults (Grenfell & Harris, 2015; Poldrack et al., 2001; Ferman et al., 2009). For example, in a complex nonword repetition task, which requires the encoding of novel phonological information. Children were able to repeat the same nonwords consistently well after an hour delay indicating that they had a stable, procedurally supported, recall of the phonological pattern. Adults' performance, however, decreased after this delay (Bishop et al., 2012). The meaningless strings of sounds in this task could be encoded implicitly as a phonological string by procedurally supported learning or they might be encoded explicitly as non-words by declarative supported learning. Potentially, the decay in adult retention of these non-words suggest that adults encoded the stimuli as less stable non-words in the task because of adult reliance on declarative learning. Children, on the other hand, may have encoded the stimuli as more-stable, phonological patterns. The increasing reliance on declarative learning with age, then, appears to come at the expense of procedurally supported learning. Evidence across second language learning and reading further point to changing roles for the procedural and declarative learning systems across language learning and language-related skills like reading.

4.1.3 Second Language Learning

Many propose that there is an advantage to language learning earlier in development when procedural learning is relatively more mature but declarative learning is immature (Anderson, 2002; Newport, 1993; Young-Scholten & Naeb, 2010; Hammick et al., 2018; Legault et al., 2018; Tarone, 2010; DeKeyser, 2008; Young-Scholten & Naeb, 2010; Grenfell & Harris, 2015). However, the role of declarative learning in second language learning increases as learners age. Specifically, as individuals age, the ability to learn phonology and syntax (supported by procedural learning) appears to decrease, while the ability to learn new vocabulary (supported by declarative learning) remains (Birdsong, 2018). Adults learning a second language for the first time will often rely on explicit learning strategies (characteristic of declarative learning) through which they rote memorize chunks of language (i.e., sentences or phrases) that match the correct grammar of their second language rather than producing sentences through implicit morphosyntactic processing (characteristic of procedural learning; DeKeyser, 1994; Roehr, K. 2004).

While declarative learning plays an important role in emergent learning, particularly for adults, procedural learning is also important for learning among adults. One study found that declarative learning supported the early acquisition of an artificial second language syntax but that, as proficiency increased, procedural learning began to support second language syntax learning. Instead of a lack of procedural support for adult second language acquisition, it seems more likely that adult learners who have difficulties with second language learning do so because they get stuck in the declarative stages of skill development and struggle to progress to the stage at which their skills proceduralize.

The importance of declarative learning for adult second language learning may also be partially attributed to the way's adults tend to learn their second language. Particularly, adults do not tend to learn in naturalistic conditions, rather they are more likely to learn their second language in a classroom. Further, the pedagogical approaches typically focus on explicit instruction and rote memorization, especially early in learning (Esteki 2014, Hu 2002). In second language learning, a learner's ability to metacognitively detect, correct, describe, and explain grammatical errors can provide a valuable foundation for future language skills, meaning that declarative support of grammar learning is a positive influence, at least initially (Green & Hecht, 1992; Renou, 2000; Renou, 2001). Explicit knowledge also provides the conceptual framework for second language learning and allows the learner to build off their own world knowledge (Lantolf & Poehner, 2011). Especially for adults, entirely implicit second language instruction is impractical without the foundation of an explicit understanding (Dekeyser 2010). Therefore, the declarative learning system's support of initial skill learning among adults is not necessarily a disadvantage and maybe, partially a byproduct of the learner's environment. However, when the explicit understanding of second language is not proceduralized, and the explicit foundation is never built upon, then the increasing declarative support of initial learning may lead to diminished language learning abilities observed among adults.

4.1.4 Reading

While reading is a complex skill, the progression of early reading and specifically decoding skills are impacted by the changing roles for memory as learners age and skills progress. Those who learn to read for the first time later in life often struggle with decoding and even skilled ex-illiterate adults are slower in their reading than children who learned earlier in life (Greenberg et al., 2002). Potentially this is due to the increasing reliance on declarative learning. For children learning to read in a second language, those with better declarative learning consolidation for a non-verbal recognition task also happened to be better readers (Sengottuvel et al., 2020) indicating that like second language learning, emergent second language reading is initially supported by declarative learning. One study found that second language learners aged 11-15 beginning to learn Mandarin characters used mnemonics and previous world knowledge (characteristic of declarative learning) to memorize a script, a manner of learning which was cognitively taxing and inefficient (Grenfell & Harris, 2015). By contrast, among kindergarteners, phonological awareness and rapid automatized naming were the most important predictors of reading Mandarin characters (Yang & McBride, 2020) which suggested that these younger readers relied more on their phonological processing and implicit automaticity for their emergent reading skills. Further, a case study using fMRI to track the development of reading-related networks in one adult emergent reader found that brain regions involved in effortful attention and associated the declarative learning continued to be engaged despite a behavioral improvement in decoding skills (Braga et al., 2017) indicating that even as skill learning progresses it is declarative, and not procedural learning, which is supporting older emergent reading. The persistent reliance on declarative learning for older emergent readers leads to a puzzling problem; If declarative-supported learning leads to inefficient emergent reading, why is this the system which, according to the DPM, supports learning among older learners?

4.1.5 Compensation and competition

At least in part, the difficulties faced by adolescent emergent readers is likely linked to the developmental changes across memory systems, particularly as the maturation of these memory systems leads to overlapping support for learning. In some circumstances, these overlapping abilities can be beneficial. Declarative learning is believed to compensate when procedural learning is impaired by supporting learning for typically procedurally supported skills (Lum et al., 2013; Ullman & Pullman, 2015; Perez et al., 2012) Among children with dyslexia, better readers also demonstrated better declarative learning indicating that declarative learning compensated for the role of impaired procedural learning in reading (Hedenius et al., 2013).

In typically developing individuals, the overlap between declarative and procedurally supported learning may result in competition between the two systems (Ashby & Maddox, 2011; Poldrack & Packard, 2003; Sherry, & Schacter, 1987). Some evidence for declarative competition with procedural learning among adults comes from second language learning (Morgan-Short et al., 2014; Ullman, 2015). In one study using a productive grammar task, multilingual individuals with aphasia affecting the basal ganglia (a region associated with procedural learning) omitted more grammatical function words in their first language (learned early in life) than their second language which they acquired later, (Fabbro & Paradis, 1995), supporting the premise that abilities associated with procedural learning, such as syntactic abilities, are supported by the declarative system when learned later in life, even when the procedural learning system is intact. Neuroimaging work has demonstrated that activation from declarative-associated regions is anti-correlated with the activation of procedurally-associated regions for well-learned skills, but competition between the memory systems can be observed through coactivation of these regions with unfamiliar information (Freedberg et al., 2020; Poldrack et al., 2001; Mattfeld & Stark, 2015) indicating that the earlier stages of learning in particular are vulnerable to competition between the declarative and procedural systems (Freedberg et al., 2020; Mattfeld & Stark, 2015; Quam et al., 2018).

The language-related skill learning as supported by declarative learning is qualitatively different from the same skills supported by procedural learning, just as the representations encoded by declarative learning and procedural learning are qualitatively different from one another (Squire 1992; Squire & Zola, 1998; Squire et al., 2004; Squire & Dede, 2015). One study found that both higher procedural learning and higher declarative learning were related to the ability of adults to learn the rules in an artificial language's morphology. Individuals who demonstrated poorer procedural learning, regardless of their declarative learning, were unable to learn complex morphological patterns (Ettlinger et al., 2014; Birdsong, 2018) indicating that a learner's relative weakness in procedural, and not declarative, learning contributes to difficulty in learning the structural aspects of language. The results of this study demonstrate that, in spite of the increasing maturity of declarative learning and it's increasing role in skill learning with age, the aspects of language which are supported by procedural learning in children (i.e., phonological and morphosyntactic acquisition) remain best supported by procedural learning in adulthood.

In reading as well, older learners demonstrate an increased reliance on declarative learning relative to younger learners. For example, an artificial word reading task demonstrated that adults continued to apply explicit word and letter learning for their emergent reading even when these strategies lead to slower and less automatic decoding (Bitan & Karni, 2004), suggesting that the initial support of declarative learning in early skill learning does not always transition into a more developed, proceduralized, skill. While structural language skills such as phonological awareness continue to support emergent reading regardless of age (Jiménez & Venegas, 2004; Durguno-lu & Öney, 2002), declarative learning, not procedural, appears to support novel phonological awareness skills in adults (Arthur et al., 2021) suggesting that fundamental reading skills which were supported by procedural among children are supported by declarative learning among adults. To summarize, declarative learning, instead of procedural learning, supports learning among older learners and it does so imperfectly and inefficiently.

4.2 The context of the study

Most literacy studies to date have not been equipped to answer questions regarding the impact of memory development on emergent literacy across development because the lion's share of research has focused on those learning to read within the context of HICs where reading instruction begins in early childhood (i.e., ages 5-7; Newport, 1990; Kuhl, 2011). In Côte d'Ivoire, many children do not start their journey to literacy until later in childhood (i.e., beyond 8 years of age) and many of these children finish elementary school without attaining basic reading abilities (Heugh, 2011). Additionally, many children do not speak the language of education (i.e., French) in their homes and begin learning French when they enter school. It is important to understand the learning needs of adolescent emergent readers in LMICs, particularly as the DPM proposes that memories' role in learning changes as an individual ages.

The context of Côte d'Ivoire provides an ideal arena to test hypotheses regarding the relative contributions of procedural and declarative learning to reading as an individual ages. Specifically, to what extent do adolescent emergent readers rely on procedural and declarative learning to support reading? Older readers have more developed declarative learning, thus, more capacity for rote memorization. Emergent readers, including children, likely use rote memorization as supported by declarative learning to learn the initial sound/letter combinations (Earle et al., 2020). Beyond this, older children might also memorize the written representations of whole words or chunks of words to circumvent decoding (Ullman & Pullman, 2015), potentially similar to the declarative compensation observed in children with dyslexia (who have an impaired procedural system). Additionally, children learning in their second language are also expected to rely more of declarative learning for their second language skill. The context of Côte d'Ivoire and the adolescent emergent readers there, allow for the examination of declarative compensation/competition among typically developing older children.

4.3 Current Study

Is emergent reading supported by the same memory systems in older and young children? It might be that all typically developing emergent readers depend on the procedural system to support decoding regardless of the relative maturation of declarative learning and the availability of rote-memorization strategies for older emergent readers, as suggested by the results found in Chapter 2 of this dissertation. Or, as suggested by the observations from individuals with dyslexia and older second language learners, it might be that older typically developing emergent readers depend on the declarative system to support decoding despite rote-memorization strategies being less efficient and more effortful. The primary aim of this study is to evaluate the two competing hypotheses which emerge regarding the role of procedural learning and declarative learning in emergent reading; 1) Declarative learning, as the system which supports early memorization sound-to-symbol mappings and later whole word learning may have more of an influence over emergent reading as the reader's age of first reading exposure increases. Because of the interference of more mature declarative learning with the proceduralization of emergent reading, declarative learning may have a negative impact on emergent readers who started school at an older age, but less of an impact on readers who started school at a younger age. Alternatively, 2) Declarative competition may not be present and procedural learning, as the system which supports early automization of sound-to-symbol mappings, may be vital for emergent reading regardless of the age at which a child first begins learning to read. Procedural learning skills, regardless of declarative learning skills will, therefore, be an important predictor of emergent reading across all ages.

Under the first of these hypotheses, early reading development for children who start school at an older age is hampered by less reliance on procedural learning and its capacity to generate expectations for sequenced events (i.e., repeat exposures) which fosters phonological awareness (Cohen, Poldrack, & Eichenbaum, 1997; Conway & Pisoni, 2008; Goschke, Friederici, Kotz, & Van Kampen, 2001; Warker, 2013). As children age and their declarative learning system matures, declarative learning competes with procedural learning to support reading acquisition. Early reading development among adolescent emergent readers begins to depend more on declarative learning and its capacity to support the rote memorization of information and events after as little as one exposure which may, in turn, support explicit memorization of the orthography-to-semantic mappings or smaller grain-sized grapheme-to- phoneme mappings, a less efficient form of phonological awareness. Age at the start of schooling will, therefore, moderate the relation between memory and reading such that procedural learning will predict better reading but this relationship may be weaker as readers' age at the start of schooling increases. Declarative learning may also predict poorer reading because of its competition with procedural learning and this relationship may be stronger as readers' age at the start of schooling increases.

Further, Chapter 2 demonstrated that, without consideration for the effect of declarative learning, procedural learning moderated phonological awareness' support of letter reading. Procedural learning, therefore, appears to play an important role in adolescent emergent reading, a role which has been previously alluded to in literacy research but for which very little evidence has been produced. A secondary aim of this study is a replication of the interaction between phonological awareness and procedural learning on reading. The opportunity to replicate the findings of Chapter 2 will provide further evidence that procedural learning's support of phonological awareness is indeed a vital for older emergent readers. If evidence of declarative competition is produced under the primary aim of this study, a replication for the role of procedural learning will demonstrate the nature of that competition, such that declarative learning interferes with procedural support of phonological awareness. Together, the primary and secondary aims of this study may provide a full test of the unique roles of declarative and procedural learning in adolescent emergent reading.

4.3.1 Participants

Ninety children from 15 French monolingual schools attending the equivalent of 6th grade in the Adzopé region of Côte d'Ivoire participated in this study. Two children were removed from further analysis because they were missing measures of declarative learning. Children ranged in age from 10-16 years. 37 of these children reported that at least one French speaking adult lived in their home. Children were participating in a larger literacy study taking place in their schools and were randomly selected in an effort to maintain equal numbers of boys and girls.

The replication was conducted using random age-matched subsets from Chapter 2 (34 fifth graders aged 10-15) and the current study (34 sixth graders aged 10-15).

4.4 Materials

4.4.1 Children's Memory Scale

Measures of declarative learning were collected using the adapted CMS (Cohen, 1997; see Chapter 3 for details on adaptation).

Dot Location is a measure of declarative, non-verbal spatial memory. Children are shown a picture of a 4X4 grid with a pattern of 8F dots located in the squares for 5 seconds. The picture is removed and the child is asked to recreate the pattern they just saw on an empty grid, using plastic tokens. The experimenter provides feedback on the correct location of misplaced tokens. Then the experimenter clears the board and asks the child to recreate the pattern again. The child is then shown a distractor pattern of different color dots in different locations on the grid. The child is asked to recreate this distractor pattern. The experimenter provides feedback on misplaced tokens, then clears the board and asks the child to recreate the distractor pattern again. After the second time producing the distractor pattern, without representing the picture of the first pattern, children were then asked to reproduce the initial pattern once again; initial recall. After a delay of about 20 minutes, the children are again asked to reproduce the initial pattern; delayed recall. A point is awarded for each dot in the correct location for the initial recall score and the delayed recall score.

During **Word Pairs**, children passively listen to a list of 9-word pairs such as 'rice/chair'. After a pause of 5 seconds, children are asked to recall half of the list by being prompted by the target word's pair: "which word goes with rice?" This is repeated a further two times with the pairs remaining the same but their order in the list changing randomly. Children were given feedback in every trial and, when necessary, provided with the correct answer. The three total repetitions of the list of word pairs were followed by immediate recall during which children were then asked to recall the word pair for each word but were given no feedback.

During **Faces**, children watched an 8-second video in which they saw 16 young and old faces of individuals. Each face was on the screen for only two seconds. Children were then given an immediate recall task in which they looked at 48 faces in a slide show, including 50% new faces and 50% from the video. The children were asked if they remember seeing each face before.

During **Word List**, children learn a list of 10 unrelated words over four learning trials. The child's goal during this task is to recall as many words as possible in any order from a list of 10 unrelated words read out by the experimenter. The experimenter reads the list slowly to the child and then asks the child to repeat back all of the words. If the child misses a word the experimenter reminds the child of the missed word. This process repeats four times. The experimenter reads the child a new list of ten unrelated words and has the child repeat that list back. The child hears and then repeats the second list a total of four times. The child is then asked to recall the original list; immediate recall. After a delay of about 20 minutes, the child is again asked to remember the first list of words; delayed recall. The number of words remembered across the first five trials are added to the child's learning score. Additionally, the number of words recalled at the immediate recall and delayed recall provide the child's immediate and delayed memory scores.

After children completed all of their initial recall tasks they completed a measure of procedural learning, the SRTT (see Chapter 2), which meant that the child remained with the experimenter during this delay. Additionally, because the task consistently takes around 20 minutes to complete, it allowed the experimenter to easily ensure that each child had roughly the same delay between the initial and delayed measures of the CMS. Once the SRTT was complete, children completed the delayed recall task for Dot Location, Word Pairs, and Word List. There were also delayed recognition tasks for Word Pairs and Faces during which the children answered whether or not they remembered seeing or hearing certain items before.

4.4.2 Serial Reaction Time Task (SRTT)

A shortened, tablet-based, serial reaction time task was used to collect the measure of procedural learning (SRTT; Clark & Lum, 2017a; Clark & Lum, 2017b; Earle et al., 2020; Hunt & Aslin, 2001; Nissen & Bullemer, 1987; see Chapter 2 Study 1). This task was shortened by reducing the number of trials during the sequenced encoding phase from 320 to 160, reducing the number of blocks from 11 to 6. Shortening the SRTT was intended to avoid boredom and consequent lack of compliance in completing the task as observed in Chapter 2 of this dissertation. Shorter SRTTs have been preferred in use with younger children by other researchers (Lum, 2010).

The transitional probability remained the same with the smiley face appearing in a sequence of positions where the transitional probability between positions was reduced from four possible positions (25%) to three possible positions in every trial (33%) by excluding the previous position. The sequential trials were followed by another 40 trials (Block 6) of the smiley face appearing in a random location. Children who have learned the sequence in Blocks 2-5 will predict the next location of the smiley face based on that learned sequence, and decrease their reaction time over the sequenced blocks. When the learned sequence no longer applies (i.e. Block 6), children may continue to make predictions as if the smiley face was still following the sequence and thus increase their reaction time for the random blocks. The change in reaction time from the last block of the sequenced trials (Block 5) to the block of random trials (Block 6) provides a measurement of procedural learning.

4.4.3 Language and Demographic Measures

Finally, the measures of literacy (i.e., word reading, letter reading, and non-word reading; RTI International, 2009), and demographic information (i.e., SES; RTI International, 2009) were collected using the same methods previously described in Chapter 2. The measures of language (i.e., phonological awareness and vocabulary; Woodcock, McGrew, & Mather, 2001; Mousty, Leybaert, Alegria, Content, & Morais, 1994), were similar to Chapter 2 but expanded. For vocabulary there were 10 antonyms and 10 synonyms (Woodcock, McGrew, & Mather, 2001). The phonological awareness tasks included initial phoneme deletion (Bruce, 1964) and word segmentation (Yopp, 1995), as well as final phoneme deletion (Bruce, 1964), and initial phoneme identification (EGRA; RTI International, 2009, Gove, 2011). There were ten items for each of the phonological awareness subtests, 40 items total.

4.5 Protocol

Approval for the study was obtained from the University of Delaware IRB, as well as from the Ivorian Ministry of Education. Consent was obtained from school directors, village chiefs, and the parent representative group (COGES); see Jasińska and Guei (2018) for detailed information about community consent procedures developed for the Ivorian context. Data collection was scheduled to suit the schedule of the village and the school.

All experimenters were native speakers of Ivorian French with a bachelor's degree or above in a relevant field. Testing took place on school property outside the child’s classroom. After assenting to take part in the study, children completed all tasks for the current study (CMS and SRTT) as well as the larger literacy intervention (demographic questionnaires, language, and literacy assessments) during their normal school hours. The entirety of the testing lasted for roughly two hours per child. For tasks included in this study, the testing time was roughly one hour. Children received a small gift, such as a book, for their participation.

4.6 Statistical Analysis

Statistical analysis was conducted using R Studio (RStudio Team, 2015). The R packages ‘plyr’ (Wickham, 2011) and ‘tidyverse’ (Wickham, 2019) were used for data cleaning and transformation. Correlations for testing the relationship between variables were conducted using the R package ‘psych’ (Revelle, 2019). Tables were generated using ‘apaTables’ (Stanley & Spence, 2018). Regressions to examine the effects of age, phonological awareness, vocabulary, declarative learning, and procedural learning on reading were also conducted using the R package ‘stats’ (R Core Team, 2012). Simple slope analysis to examine interactions between two continuous variables was conducted using ‘pequod’ (Mirisola & Seta, 2016), ‘sjmisc’ (Lüdecke, 2018), and ‘reghelper’ (Hughes, 2020). The Johnson-Neyman Interval analysis, to examine significant three-way interactions, was conducted using the ‘interactions’ package (Long, 2019). Visualizations were generated using the ‘ggplot2’ (Wickham, 2016), ‘sjPlot’ (Lüdecke, 2018), ‘interactions’ (Long, 2019), and ‘ggpubr’ (Kassambara, 2020) packages.

For the SRTT task, inaccurate trials were discarded (2.81% of trials). The number of discarded trials (incorrect or no response) for individual children ranged from 0 to 59 (M=6.58, SD=9.99). For analysis, the reaction times for each block were log transformed in order to correct for right skew and to standardize across subjects. After the log transformation, trials with reaction times three standard deviations above or below the mean for each individual child were also discarded. The procedural learning score was determined by subtracting a child’s logged mean reaction time in the 5th block (the final sequenced block) from the logged mean reaction time in the 6th block (return to random pattern after sequenced).

For the replication of Chapter 2, age-matched subsets were generated by randomly selecting participants from the sample from Chapter 2 and the sample from Chapter 4 using the R base package (R Core Team, 2023).

4.7 Results

In the first part of this analysis, I present descriptive results for each individual measure; Demographic) age, age at school start, and grade repetition. Language) phonological awareness and vocabulary. Literacy) letter, word, and non-word reading. And, Memory) Declarative and Procedural. Additionally, I present the statistical relationships between these measures.

To understand how each individual's reading ability is influenced by either procedural or declarative learning, in the second part the analysis investigates whether age at school start moderates the relation between procedural or declarative learning and reading using a multiple linear models to examine the interactions between age at school start and declarative learning on reading, and age at school start, procedural learning and phonological awareness, with the additional main effects of phonological awareness and vocabulary. For significant interactions, a simple slope analysis is used as a post-hoc test to determine the nature of the moderation.

4.7.1 Age at School Start and Grade Repetition

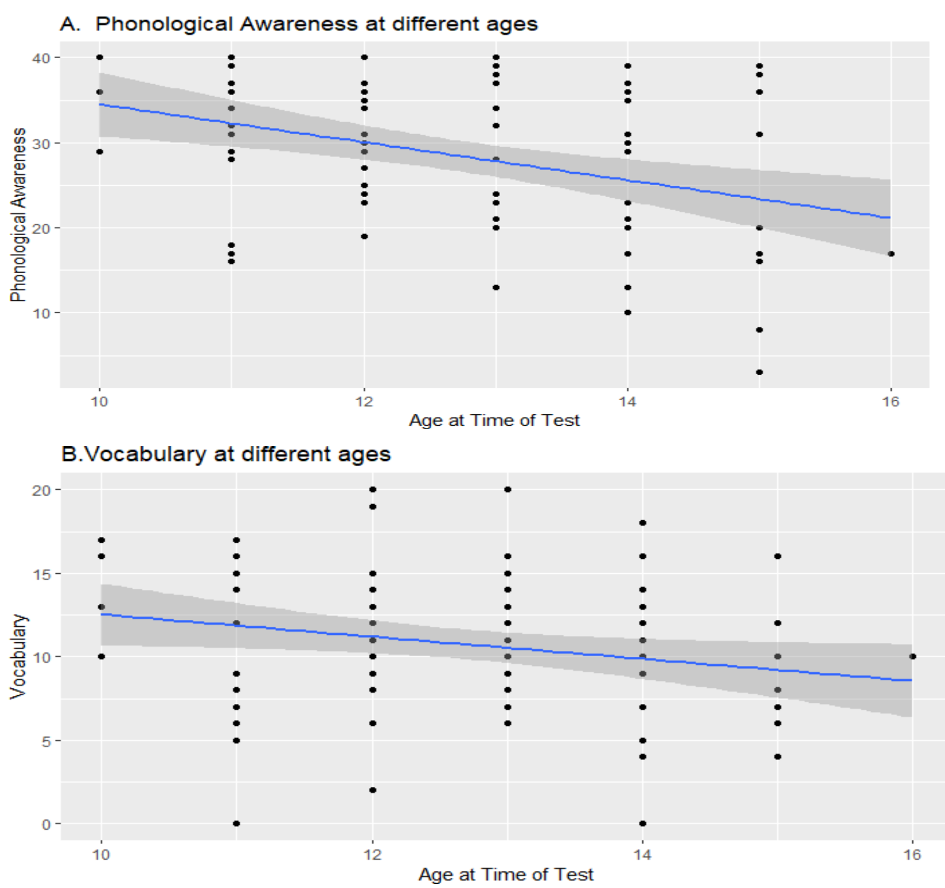
Though the children in this sample were all in the same grade level their ages varied, as is common in Côte d'Ivoire due to children entering school at varying ages and often repeating grades. The number of grade repetitions and the age at which the child entered school serve as indicators of the child's educational experience and age of exposure to literacy instruction. The age at which a child entered school ranged from 4 to 9 years of age (table 4.1.) and was correlated with the age at the time of testing (r (81) =0.81, p>0.001) letter reading, and word reading (figure 4.3). Grade repetitions were not uncommon. Some children never repeated a grade (53.09% of children), while others repeated it up to three times (6.17% of children; table 4.1). The number of grade repetitions was negatively related to several factors including phonological awareness, vocabulary, letter reading, word reading, non-word reading, and procedural learning (figure 4.3).

4.7.2 Age and Language Skills

The presences of a French speaking adult in the home was not correlated with either of the language measures (i.e., vocabulary or phonological awareness). The presences a French speaker in the home was also not correlated with any of the literacy measures (i.e., Letter Reading, Word Reading, or Nonword reading).

There was a modest negative correlation between vocabulary and age ($r(85)=-0.23$, $p=0.03$; see Figure 4.1A). Phonological awareness was negatively correlated with age (r (84) =- 0.37, $p<0.001$; see Figure 4.1B). There was also a marginally significant negative correlation between age at school start and phonological awareness (r (84) =-0.2, $p=0.08$) but no significant correlation between age at school start and vocabulary ($p=.4$)

Figure 4.1: A. Phonological awareness at different ages. B. Vocabulary at different ages.



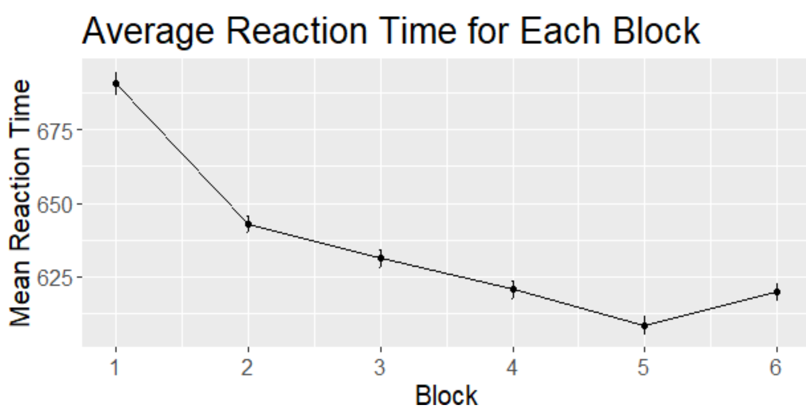
4.7.3 Memory

The average, standard deviation, and range for each individual sub-task in the CMS is reported in table 4.2 below. In order to combine the scores of the declarative learning subtests which do not have the same distributions, each of the subtests was converted to a z-score. The z- scored subtests were added together to form the composite scores; Verbal Immediate: Word List Immediate Recall and Word Pairs Immediate Recall, Verbal Delayed: Word List Delayed Recall and Word Pairs Delayed Recall, Visual Immediate: Dot Location Immediate Recall and Faces Immediate Recall, Visual Delayed: Dot Location Immediate Delayed and Faces Delayed Recall, and the Total Declarative learning Composite of all subtests, as this was how the composite score was calculated in the original CMS. Many of the sub-tests were correlated with one another (see figure 4.3). Initial Dot Location was correlated with initial Word Pairs and Delayed Dot Location. Initial Word List was correlated with Initial Word Pairs, Delayed Dot Location, Delayed Word Pairs, and Delayed Word List. The Initial Faces task was only correlated with Delayed Faces. The mean accuracy during training for Dot Location was 73.77% (SD=12.65%). The mean accuracy during training for Word Pairs was 25.30% (SD=11.57%). The mean accuracy during training for Word List was 38.98% (SD=12.65%). The mean accuracy during the initial phase of Faces was 67.37% (SD=11.63%).

In spite of the relatively high accuracy for Dot Location training among this subset of the children, Chapter Three of this dissertation reported low reliability in the Dot Location task, potentially because of the poor ecological validity of the task. Additionally, accuracy for the two verbal tasks was low. For both tasks the performance was below chance for many children (see table 4.1). As Chapter Three points out, these tasks may rely on a child's knowledge of French. Indeed, with the exception of Initial Word List, the verbal tasks were correlated with vocabulary while the visual tasks were not (see figure 4.3). If a child's knowledge of French was poor then this would be an issue for their performance in the verbal tasks. In light of these considerations, only the Faces scores were used in the remainder of the analysis. The Faces task was not correlated with either phonological awareness or vocabulary (figure 4.3).

The procedural learning score in the SRTT task was derived by subtracting the mean logged reaction time of trials in the final sequenced block (block 5) from the mean logged reaction time of trials in the block that switched to a random pattern (block 6). A mixed effects model with a random intercept for the subject and with random slopes for each subject, to examine the differences in reaction time for random and sequenced conditions found that the conditions were significantly different (b=-11.02, t(6687.25)=-3.19, p=0.001). Figure 4.2 shows that overall children did become faster as they learned the sequence. Procedural learning was correlated phonological awareness and vocabulary (figure 4.3).

Figure 4.2: The mean reaction time for the SRTT at each block.



Error bars represent standard errors.

4.7.4 Memory and Age

Procedural learning was not correlated with age or age at school start, it was however negatively correlated with grade repetition (figure 4.3). For declarative learning (Faces Initial and Delayed) there was marginal negative correlation with age but not grade repetition or age at school start.

Figure 4.3: Correlations of measures including the Verbal and Visual composite score for Declarative learning.

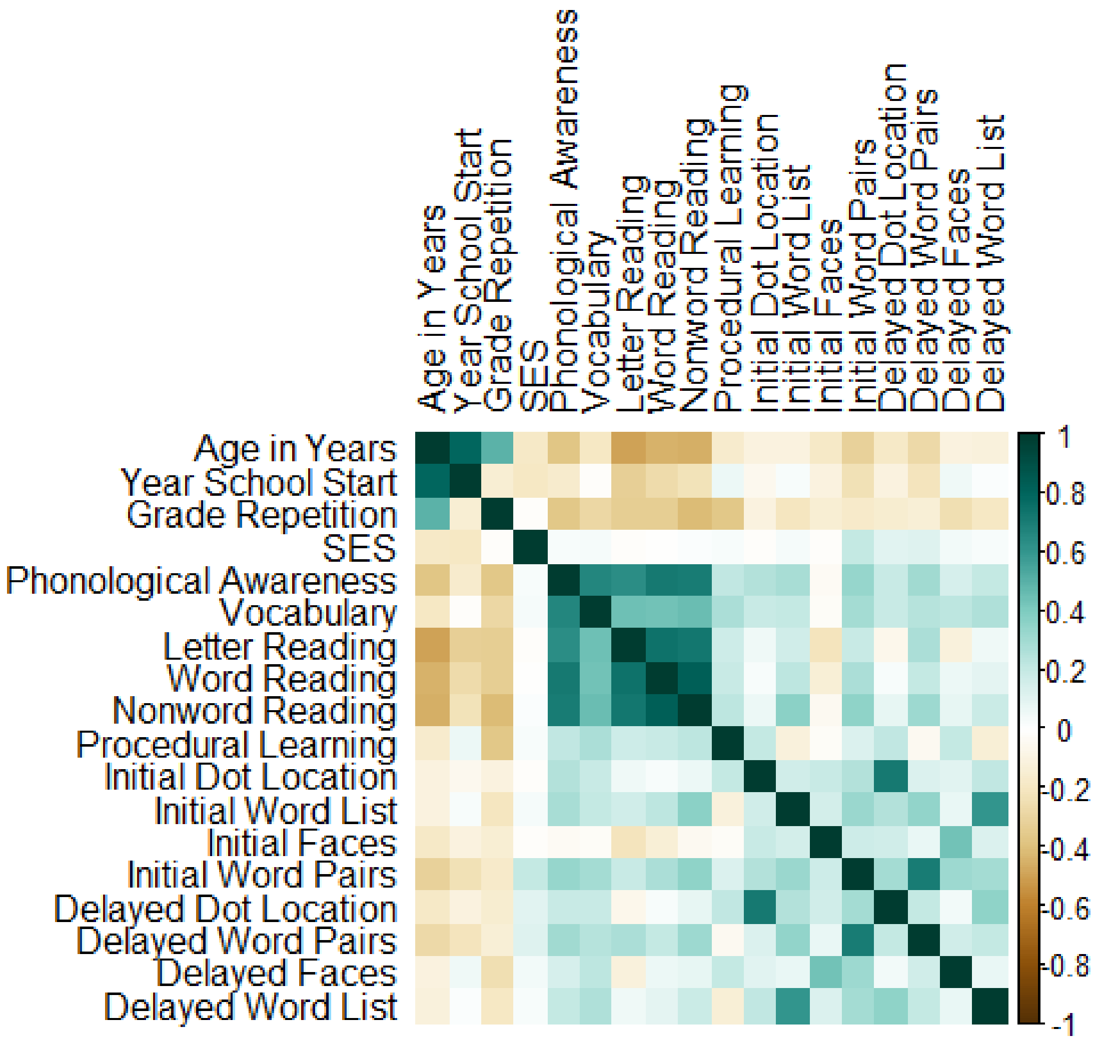


Table 4.1: Means and Standard Deviations for all measure totals.

Measure	M	SD	Min.	Max.
Age	12.70	1.47	10	16
Age at School Start	4.98	1.33	3[i]	9
Grade Repetition	0.72	0.88	0	3
Socioeconomic Status (0-15)	6.91	2.55	0	13
Phonological Awareness (0-40)	28.55	8.88	3	40
Vocabulary (0-20)	10.73	4.22	0	20
Declarative learning Raw Total	101.65	12.16	78	130
Procedural learning	0.02	0.08	-0.39	0.20
Letter Reading (0-100)	61.6	21.48	0	100
Word Reading (0-50)	34.71	15.8	0	50
Nonword Reading (0-50)	28.55	8.88	3	40

Table 4.2: Means and Standard Deviations for raw scores on Declarative subtests.

		Measure	M	SD	Min.	Max.
Visual	Dot Location (0-8)	Immediate	5.45	1.46	0	8
		Delayed	5.44	1.42	0	8
	Faces (0-24)	Immediate	13.99	4.86	0	23
		Delayed	14.60	5.25	2	24
Verbal	Word Pairs (0-14)	Immediate	3.68	1.88	0	10
		Delayed	2.81	1.68	0	9
		Recognition	12.70	1.50	8	14
	Word List (0-14)	Immediate	5.27	2.21	1	10
		Delayed	4.89	2.36	0	11
Total Declarative learning Raw Score			56.14	12.08	25	92

[i] Note that, as may children could not report the month of their birth, ages were recorded as whole numbers. Because of this the calculation for age at school start may not be the precise age. It is unlikely that a child actually entered school at age three, rather children whose age at school start is 3 were likely young four-year-olds at the time of entering school.

4.7.5 The Impact of Procedural and Declarative Learning on Literacy

A moderated regression with residual centering estimated the effect of socioeconomic status, grade repetitions, age at school start, phonological awareness, vocabulary, procedural learning, declarative learning (Faces Initial and Delay), Two-way interactions between phonological awareness and procedural learning, age at school start and procedural learning. Age at school start was used as opposed to age at time of testing as this is the measure of the child's age at their first experience with reading, and, together with grade repetition it is a clearer measure of amount of educational experience. Each of the variables were centered as they were on different scales.

For letter reading, there were significant main effects for grade repetition, age at school start, phonological awareness, and declarative learning. There was a marginal two-way interaction between age at school start and declarative learning (see table 4.3). For word reading there were significant main effects for age at school start and phonological awareness and a marginal main effect for grade repetition (see table 4.3). For nonword reading there were significant main effects for grade repetition and phonological awareness and a marginal main effect for age at school start. There were no significant interactions (see table 4.3).

Simple slopes analyses were used to further examine the two-way interaction between age at school start and declarative learning, see figure 4.4. For children who started school at a younger age (one standard deviation below the mean), declarative learning significantly predicted letter reading ($b=-0.90$, $t(63)=-3.81$, $p<0.001$). For children who started school at an older age (one standard deviation above the mean), declarative learning did not predict letter reading ($p=.31$). These simple slopes indicate that declarative learning scores increased with the age of the child but that declarative learning itself was detrimental to reading ability, however, as the interaction was marginal it should be interpreted with caution.

Figure 4.4: Simple slope analysis of letter reading's relation to age at school start at different levels of declarative learning.

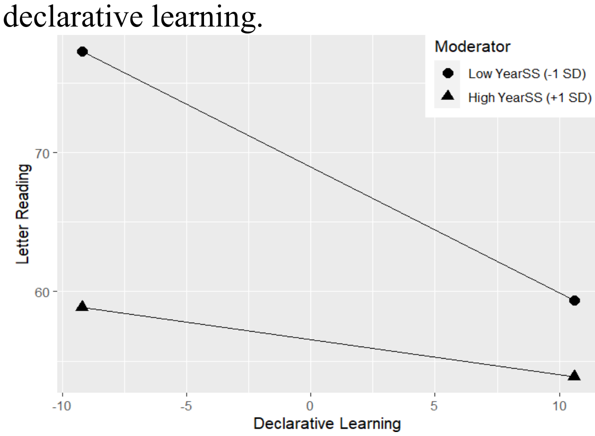


Table 4.3: Regression results for letter reading, word reading, and nonword reading.

Predictor	Letter Reading β	Word Reading β	Nonword Reading β
SES	-0.06	-0.04	-0.02
Grade Repetition	-0.28 **	-0.18 .	-0.25 *
Year School Start	-0.29 ***	-0.20*	-0.16 .
Phonological Awareness (PA)	0.49 ***	0.67***	0.60 ***
Vocabulary	0.03	-0.09	-0.04
Procedural Learning (PL)	-0.05	0.09	0.05
Declarative Learning (DL)	-0.25 ***	-0.08	-0.04
PA: PL	-0.09	0.01	-0.004
Year School Start: PL	-0.09	0.14	0.02
Year School Start: DL	0.15 .	0.08	0.39
Fit	R^2=0.60 *** Adjusted R^2=0.54	R^2=0.57 *** Adjusted R^2=0.51	R^2=0.56 *** Adjusted R^2=0.49

. *indicates p<.1 * indicates p < .05. ** indicates p < .01.* *** indicates p<.001

4.7.6 The Interaction of Procedural Learning and Phonological Awareness

To explore whether the procedural learning by phonological awareness interaction reported in Chapter 2 was replicated in the independent dataset collected in Chapter 4, the same analysis reported in Chapter 2 (Model: reading ~

phonological awareness: procedural learning) was run on age-matched subsets of children from Chapter 2 and Chapter 4 (see Table 4.4). The sample reported in Chapter 2 contained fifth-grade children who were younger than the sixth- grade sample reported in Chapter 4 and the sample reported in Chapter 4 contained sixth-grade children who were older than the fifth-grade sample reported in Chapter 2, therefore age- matched subsets from the Chapter 2 and Chapter 4 samples were used. Between the two samples (Chapter 2, Chapter 4), the age at school start was significantly different ($t(62.79)=-7,18$, $p>.001$), but the number of grade repetitions were not significantly different between the two samples ($p=.72$). Comparing the reading scores between the two samples, letter reading scores were significantly different ($t(32)=19.85$, $p>.001$) and word reading scores were significantly different ($t(64.00)=6.79$, $p>.001$). Finally, comparing the language skills between the two samples, phonological awareness scores (out of 10 items for Chapter 2 and 40 items for Chapter 4) were significantly different ($t(37.70)=17.62$, $p>.001$) as were vocabulary scores (out of 10 items for Chapter 2 and 20 items for Chapter 4; $t(41.9)=7.81$, $p>.001$).

Table 4.4: Means and Standard Deviations for all measure totals.

	Mean *Chap. 2*	SD *Chap. 2*	Mean *Chap. 4*	SD *Chap. 4*
Age	11.62	1.33	11.62	1.33
Age of School Start	6.12	1.17	4.29	0.68
Grade Repetition	0.53	0.61	0.60	0.82
Letter Reading	25.62	20.19	66.70	20.81
Word Reading	12.09	14.22	36.30	14.58
Procedural Learning	0.02	0.10	0.02	0.10
Phonological Awareness	2.15	2.65	30.33	8.54
Vocabulary	3.09	2.07	10.58	5.12

For letter reading with the subset from Chapter 2, there was a main effect of vocabulary and a marginal main effect of phonological awareness as well as significant interactions for procedural learning and phonological awareness and a marginal interaction for procedural learning and vocabulary, matching the previous results from Chapter 2 (see Table 4.5). For letter reading with the subset from Chapter 2, there was only a main effect for vocabulary (see Table 4.5). For word reading with the subset from Chapter 2, there was only a main effect of phonological awareness. For word reading with the subset from Chapter 4, there was a significant main effect of grade repetition and a marginal main effect of phonological awareness, and significant interactions for procedural learning and phonological awareness, and for procedural learning and vocabulary.

Simple slopes analyses were used to further examine the two-way interaction between procedural learning and phonological awareness on letter reading for the subset from Chapter 2. For children with poorer procedural learning, the slope of phonological awareness was not significant ($p=.20$). For children with better procedural learning, phonological awareness significantly predicted letter reading ($b=0.97$, $t(24)=3.16$, $p>.001$), indicating that children with better phonological awareness were also better letter readers.

Simple slopes analyses were also used to further examine the two-way interaction between procedural learning and phonological awareness on word reading for the subset from Chapter 4. For children with poorer procedural learning, the slope of phonological awareness was not significant ($p=.20$). For children with better procedural learning, phonological awareness significantly predicted letter reading ($b=1.09$, $t(21)=3.41$, $p>.001$), indicating that children with better phonological awareness were also better word readers.

Table 4.5: Regression results predicting variations in letter reading with subsets of samples from Chapter 2 and Chapter 4.

	Letter Reading *Chapter 2*	Letter Reading *Chapter 4*	Word Reading *Chapter 2*	Word Reading *Chapter 4*
Predictor	β	β	β	β
SES	-0.01	0.22	0.004	0.13
Age at School Start	-0.02	-0.11	0.03	-0.09
Grade Repetition	-0.10	-0.23	0.04	-0.51 **
Procedural Learning (PL)	-0.08	0.15	-0.11	-0.20
Phonological Awareness (PA)	0.33 .	0.10	0.51**	0.35 .
Vocabulary	0.37 *	0.55 *	0.26	0.28
Age: PL	0.07	0.25	-0.005	0.11
PL: PM	0.65 **	0.54	0.20	0.71 **
PL: Vocabulary	-0.63 .	-0.22	-0.21	-0.30 *
Fit	R^2= 0.52 ** Adjusted R^2= 0.34	R^2= 0.60 * Adjusted R^2= 0.42	R^2= 0.48 * Adjusted R^2= 0.29	R^2= 0.76 *** Adjusted R^2= 0.66

'***' indicates p <.001. '**' indicates p < .01. '*' indicates p < .05. '.' indicates p <.1

4.8 Discussion

It was the intention of this study to examine whether or not the role of procedural and declarative learning changed as emergent readers aged to adjudicate between two competing hypotheses: 1) Declarative learning, as the system which supports early memorization sound-to- symbol mappings and later whole word learning may have more of an influence over emergent reading as the reader's age of first reading exposure increases. Because of the interference of more mature declarative learning with the proceduralization of emergent reading, declarative learning may have a negative impact on emergent readers who started school at an older age, but less of an impact on readers who started school at a younger age. Alternatively, 2) Declarative competition may not be present and procedural learning, as the system which supports early automization of sound-to-symbol mappings, may be vital for emergent reading regardless of the age at which a child first begins learning to read. Procedural learning skills, regardless of declarative learning skills will, therefore, be an important predictor of emergent reading across all ages. In general, these results point towards the first hypothesis: declarative learning appears to have a negative relation with reading.

Overall, these results continue to point towards poorer outcomes for adolescent emergent readers. In part, the increased difficulties in acquiring reading with age may point to changing cognitive development (including memory development), which may qualitatively change how older children learn. Throughout development, an individual may pass through periods during which they experience an advantage for certain types of learning (i.e., sensitive periods). Sensitive periods have been proposed for many aspects of cognitive development including but not limited to; second language learning (Lenneberg, 1967; Newport & Johnson, 1989; Birdsong, 1999; Newport & Johnson, 1989), episodic memory (Laube et al., 2020; Fandakova et al., 2017), executive functions (Thompson & Steinbeis, 2020), and potentially reading (Young-Scholten et al., 2006). The exit from many of these sensitive periods have often been linked to the entrance into puberty, potentially as changing hormones may affect neural plasticity (Laube et al., 2020; Fandakova & Hartley, 2020). Another potential explanation for these sensitive periods may be that cortical specialization, once established, can compete with new learning. For example, the neural areas involved in object recognition which are specialized for reading among skilled readers, face an initial competition between pre-existent object recognition specialization and developing specialization for reading among older first-time readers (Dehaene et al., 2010).

On the other hand, as domain-general cognitive abilities mature, older individuals have more cognitive resources for some aspects of skill learning. Indeed, the development of domain- general abilities has a reciprocal relationship as academic skills and executive functions develop in tandem (Fuhs et al., 2014). As declarative learning develops so does an individual's world knowledge providing learners with increasingly intricate scaffolds for encoding further semantic knowledge (Murphy et al., 2021). The increasing maturity of declarative learning and its apparent negative link with reading suggests an important role of declarative learning in adolescent emergent reading, however, no work (to the best of my knowledge) has yet examined the specific contributions of declarative and procedural learning among emergent readers in late childhood and adolescence.

4.8.1 Reading and Age

Consistent with previous work in the same context, children who started school at a later age were poorer readers. Additionally, factors which likely contributed to a child being older but still in the sixth grade, grade repetition, was also negatively associated with reading skills. In general, being an older emergent reader, despite potentially having relatively longer experience with literacy (e.g., though grade repetition) was worse for reading outcomes indicating that the timing of reading exposure might matter for later literacy success. This was true regardless of the socioeconomic status of the child, indicating further that it is indeed timing of education that drives the negative relation between age and reading. This was also true regardless of the presence of a French speaker in the child's home, and indication that the child received earlier exposure to their language of education prior to their entrance into school. The language abilities below and their respective relations to age further illuminate the potential role of timing in emergent reading education.

4.8.2 Phonological Awareness

Phonological awareness is a vital skill for emergent reading. Indeed, phonological awareness was positively correlated with all reading scores and a strong predictor of reading even when controlling for memory and age. As with reading, phonological awareness was negatively correlated with age and grade repetition. The reciprocal nature of the relationship between phonological awareness and reading might explain how individual factors such as the child's age at the start of their schooling or the number of times a child repeated a grade contribute to a disadvantage for older children in both reading and phonological awareness. Not only does phonological awareness contribute to skilled reading, but skilled reading also supports phonological awareness. As a child begins to master decoding, their metalinguistic knowledge of language will increase, better phonological awareness leads to better reading and better reading leads to better phonological awareness (Castles & Coltheart, 2004; Hogan, Catts, & Little, 2005; Wagner & Torgesen, 1987). Therefore, older children may also demonstrate poorer phonological awareness because they are poorer readers. Potentially, children who are older and still in the sixth grade are there in part due to poorer language skills and poorer academic achievement in general, which may contribute to grade repetition. Yet, it is unlikely that the negative relation between reading and phonological awareness among older children is due to these children being poorer students alone since negative relation with age and phonological awareness remained even after controlling for vocabulary and grade repetition. Additionally, the age of exposure to their language of education, as indicated by the presence of a French speak in the child's home, appears not to contribute to either a child's reading or language skills.

4.8.3 Vocabulary

Unlike phonological awareness, vocabulary was not significantly correlated with age, suggesting that lower vocabulary scores were associated with poorer academic achievement in general not age-related differences in language skill. Crucially, this contrast between vocabulary and phonological awareness points to age-related differences for phonological awareness alone. These results may provide further evidence of a sensitive period for phonological, but not semantic, learning.

4.8.4 Memory and Age

Participants in this study were 10-16 years of age, beyond the point at which most age-related differences in procedural learning would be expected. There were no age-related differences for procedural learning but, contrary to expectations, there was a negative relation between declarative learning and age. Declarative learning development particularly for visual recognition develops slowly, significant differences have been found in declarative learning development between children aged 8-12 and adolescents aged 13-17 (Ofen et al., 2007). In this sample, ages were positively skewed leading to few observations in the 13-16 age group and potentially increasing the risk of a spurious negative correlation. Additionally, declarative learning also had marginal negative relation to grade repetition. As older children were also more likely to have repeated grades the negative relation between declarative learning and age may be due to older children having poorer academic related skills more generally. The numbers of observations for older children in sixth grade was limited; there were 11 fifteen-year-olds and one sixteen-year-old; the influence of the few older children, who were also likely to have repeated grades and struggle in school more generally, may have contributed to the negative link between age and declarative learning. Declarative learning, however, was not related to the age at which a child started school, which is a measure of a child’s first experience with literacy and not related to grade repetition. Entrance to school may be a less biased measure of age.

4.8.5 Memory, Age, and Reading

Declarative learning. The faces task was not correlated with vocabulary or phonological awareness. While it might be expected that declarative learning would contribute to vocabulary, the absence of this relation is not necessarily a cause for concern, particularly as there are secondary factors which likely contribute to vocabulary in this sample including a child's knowledge of French. For reading, declarative learning was negatively related to letter reading, indicating that declarative learning was not helpful in emergent decoding, which requires a good understanding of the phoneme-to-grapheme mapping. This is contrary to previous results among children in the United States in the first grade for whom declarative learning played a valuable role in the earliest stages of memorizing phoneme-to-grapheme mapping (Earle et al., 2020). Importantly, the contribution of declarative learning for those first-grade children was interpreted as the first step in building toward more automatic, implicit, phoneme-grapheme-mapping. For older children, further along in their schooling, the rote memorization of phoneme-to-grapheme mappings may make early decoding more effortful and less successful, if they do not move beyond this initial stage of recognizing a grapheme and explicitly recalling. In other words, declarative learning might become a hindrance to reading development when its progressive maturation and increased competition with procedural learning make it difficult for children to transfer newly acquired explicit knowledge into implicit, automatic, ability.

Among sixth graders who started school at a younger age declarative learning negatively predicted letter reading. Better declarative learning, therefore, was a hinderance on reading development but among children who started school at an older, the relation was no long present. Potentially, older children who started school later, with more mature declarative memory at the time of first reading exposure, might be better able to overcome the negative impacts of declarative memory on reading. Alternatively, because reading skills were so poor among older children who started school late, the negative impact of declarative learning was just one of many factors contributing to poorer reading outcomes. The later explanation seems to be the more likely, however, since the interaction was marginal any conclusions regarding interaction between declarative learning and age of schools start should be made provisionally and with caution. What is clear regarding declarative learning's relation to reading overall is that as declarative learning skills increase the emergent reading skills among adolescents fail to flourish, such that sufficient declarative competition will stymie early reading development.

Procedural Learning. Among adolescent readers in the sixth grade, phonological awareness was positively related to procedural learning scores, as the DPM would predict. This indicates that, even among older children, procedural learning can and does support phonological awareness. Contrary to expectations, however, procedural learning and phonological awareness did not have the same interaction for letter reading as previously found (see Chapter 2). Potentially, when the negative contributions of declarative learning are considered, any positive impact of procedural learning is overshadowed. Procedural learning's negative relation with grade repetition also suggests that children whose general performance in school were poor tended to demonstrate poorer procedural learning. Procedural learning might, therefore, be strongest among children who were stronger learners in general. Indeed, procedural learning was also found to be positively related to vocabulary, suggesting that, beyond phonological processing children with better procedural learning were better language learners overall.

4.9 Procedural Learning and Phonological Awareness for Reading.

The secondary aim of this study was to establish whether findings reported in Chapter 2 would replicate in an independent sample of learners, age-matched subsets for the sample from Chapter 2 (fifth grade; age 10-15) and Chapter 4 (sixth grade; age 10-15) were created and the analysis from Chapter 2 was rerun on these subsets analyzed in Chapter 4.

There were several important differences between the samples from

Chapter 2 and Chapter 4 which should be acknowledged. First, while the sample from Chapter 4 was age matched to those in Chapter 2 their school experience was not the same. The children from Chapter 2 were in the middle of fifth grade and their data was collected in 2019 while the children from chapter 4 were finishing the sixth grade and their data was collected in 2021. Second, the language the measures were a different length in each of the subsets. The vocabulary measure was out of 10 items for Chapter 2 and 20 items for Chapter 4, and phonological awareness was out of 10 items for Chapter 2 and 40 items for Chapter 4. Finally, the SRTTs used in both analyses were not identical. For Chapter 2, the locations for the target were arrayed in an arc and there were 11 blocks and 440 total trials. For Chapter 4, the locations for the target were arrayed in a diamond pattern and there were 6 blocks and 240 total trials. The shorter SRTT as well as the diamond pattern were chosen to be easier for younger children, alleviate the need for children to return their finger to home base in between trials (see Chapter 2 Methods), and prevent boredom. There is, however, a potential advantage for a longer SRTT as this gives children more exposure to the sequence. Still, the shortened SSRT has been used successfully with children in other contexts (Lum, 2010).

Further, while the samples were age matched, children started school earlier in the Chapter 4 sample than children in the Chapter 2 sample. Selecting children in the sixth-grade age matched to children in the fifth-grade, therefore, had the unintended consequence of selecting the sixth graders who started school at a younger age. Beginning school at a younger age on average could change the influence of procedural learning on reading and phonological awareness such that younger children are more likely to rely on procedural learning for skill learning. However, children who started school at a younger age and were still in school at older age may have experienced more interruptions to their education such that they may not have the necessary consistent exposure to reading and phonological awareness to rely on procedural learning to support these skills.

The results from Chapter 2 were largely replicated on letter reading with the subset from Chapter 4. The subset from Chapter 4 did not replicate the results from Chapter 2, instead only vocabulary predicted letter reading. Potentially, children further along in their education no longer leverage procedural learning for phonological awareness. Indeed, the children from the subset taken from Chapter 4 were better readers than the children from the subset taken from Chapter 2, who were at an earlier age in their education. Letter reading requires a child to associate a grapheme with a specific phoneme without the lexical content or orthographic context of a full word. As French has consistent grapheme-to-phoneme mapping (Brice et al., *under review*), children who have progressed in their emergent reading beyond early letter recognition and initial memorization of phoneme-to-grapheme mappings and instead are learning and automatizing the decoding necessary to read words might not demonstrate an effect of procedural learning's support of phonological awareness on letter reading. Instead, because these abilities become more of an asset for less developed reading skills.

The children from the subset taken from Chapter 4 did present the interaction between procedural learning and phonological but for word reading instead of letter reading. Further, the simple slope analysis for Chapter 2's subset on letter reading matches that of Chapter 4's subset on word reading, such that children with better procedural learning are better able to leverage procedural learning's support of phonological awareness in emergent word reading. For Chapter 4's subset, children who were better readers and at a later stage in their education leveraged procedural learning's support of phonological awareness on word reading instead of letter reading. Potentially, procedural learning's influence graduates to more complex emergent reading skills as children progress through their literacy education. The influence of procedural learning and phonological awareness on word reading is particularly interesting as word reading can be accomplished through either procedurally supported decoding or declaratively supported word recognition.

Crucially, the relation between phonological awareness and procedural learning was not present in either letter reading or word reading when declarative learning and a greater number of older children were included in the regression, but it was present for word reading when fewer older children and declarative learning were not included in the regression. If older children and more experienced children face greater competition from declarative learning then it's possible that the influence of declarative learning overshadows the potential contributions of procedural learning. Further, the inclusion of older children in the analysis may mean that more of the variability on reading could be related to declarative, not procedural, learning.

Once again, the interaction between procedural learning and phonological awareness for letter reading among fifth grades, and for word reading among sixth graders provides strong evidence that procedural learning is crucial for developing reading skills. Indeed, this replication provides some of the first evidence that the DPM is correct regarding the role of procedural learning for language-related skill development, such that better readers are those who are able to proceduralize their reading skills, first with letter reading, then with word reading. Further, this replication demonstrates that the importance of phonological awareness for older emergent readers continues on past the earliest emergent reading abilities. Phonological awareness, because of procedural learning's support, is the key to effective and efficient decoding. Without replication, findings such as these do not bear the same theoretical weight, they only hint at the confirmation of hypotheses. With replication, the picture is clearer in the light of confirmatory evidence.

4.10 The 'See-Saw' Effect

The impact of declarative learning on reading appears to be one which inhibits rather than supports reading development, at least for emergent reading in adolescence. Children whose first introduction to literacy occurs earlier in life have advantages from unimpeded procedural learning as well as apparent advantages for phonological development (likely related to the unimpeded procedural learning). As the child progresses through their education, their learning systems also change.

It is likely, given the results above, that as declarative learning becomes more mature, it competes with and impedes procedural learning. However, the situation is not ‘either/or’, children whose declarative learning is more mature will also have more mature (likely plateaued) procedural learning, and therefore, procedural learning still contributes to emergent reading. The competition from declarative learning is an obstacle but not an immutable one. Likely, sufficient exposure and consistent experience are key to overcoming the declarative stopgap, proceduralization may still be possible. Take for example, the children who progressed from procedurally supported letter reading to procedurally supported word reading: these children made progress in their emergent reading, likely because the longer they were attending school the more reading exposure they received, and the more reading exposure they received the more they were able to proceduralize their skills. Likely, a consistent educational experience has a positive impact on the proceduralization of reading, indeed these results do suggest that such an impact is not only possible but present.

4.11 Conclusions

Many factors contribute to a child being an adolescent emergent reader including their age at entering school and the number of grades they repeat while attending school. These factors complicate the understanding of the roles of maturation and experience in emergent literacy, however, there is a wealth of knowledge to be gained from previously ignored corners of emergent reading. Among adolescents in Côte d’Ivoire, the memory systems which underlie language development play important roles in developing reading skills. Crucially, the respective roles of these memory systems are not identical. Declarative learning, the system which supports world knowledge, vocabulary development, and rote learning, can behave as a hindrance to learning to read at an older age, especially at the early stages of emergent reading. Procedural learning, on the contrary, is an important asset of early emergent reading which is dampened by declarative learning in older emergent readers. Potentially, emergent reading among older children requires alternate teaching strategies to mitigate the interference of declarative learning and amplify the contributions of procedural learning. Additionally, the full extent of the benefits of consistent education for amplifying the potential contributions of procedural learning should be further explored.

Chapter 5

CONCLUSIONS: PROCEDURAL AND DECLARATIVE LEARNING FOR EMERGENT READING IN RURAL COTE D'IVOIRE

5.1 The Literacy Crisis

Literacy is a vital skill, without it an individual living any industrialized society is denied economic, legal, and cultural agency. Literacy education has been identified as one of the key components to the sustainable development of low- and middle-income countries. Despite the international effort to improve literacy education, the number of projected illiterate children and adolescents worldwide is 300 million by the year 2030 (UN DESA. 2023). In Côte d'Ivoire less than half of the adult population is literate (Jasińska et al., 2023). Many children in Côte d'Ivoire who complete primary school are still functionally illiterate (Heugh, 2011). Consistent throughout this dissertation was the finding that many children, even those in the equivalent of 6th grade, struggle to decode words or appropriately associate graphemes to their phonetic representations. The answer to improving literacy, therefore, is not simply more education but better education. A one-size-fits-all approach to literacy allows children who struggle to fall through the cracks. It is crucial to understand why children struggle so that literacy education is responsive to their needs.

One factor that seems to contribute to the persistence of illiteracy is the age at which a child begins learning to read. Children preparing to enter puberty have progressed in cognitive development such that their learning abilities and instructional needs no longer match those of younger learners. In Côte d'Ivoire, the variable age at entering school appears to contribute to variable outcomes for young readers. Indeed, the findings of this dissertation demonstrate that the development of procedural and declarative learning has a measurable impact on the literacy outcomes for adolescent emergent readers. Procedural learning plays a critical role in emergent reading through its support of phonological awareness. As children progress through their education, however, declarative learning can compete with and impede the contributions of procedural learning. When children's declarative learning development outstrips their emergent literacy development, therefore, literacy development stagnates and the child does not attain literacy.

5.2 Measuring Declarative Learning in Low Technology Environments

In the pursuit of a more global understanding of reading and cognitive development to be certain that the measures designed for testing in high-income-countries (HICs) are relevant in low- and middle-income-countries (LMICs). Especially since these measures, particularly measures of declarative learning, may be culturally bound and have limited reliability among children in LMICs with different experiences and epistemic knowledge (Kolling et al, 2015; Freire & Pammer, 2019). Therefore, in order to understand the influence of declarative learning on reading in Côte d'Ivoire it is necessary to also verify that the measures of declarative learning do as they claim. Specifically, it is vital to determine the cultural validity, or the impact of a participant's socio-cultural expectations on assessment performance (Kūkea Shultz & Englert, 2021; Solano-Flores, 2011), for any measure of declarative memory in a new context. Additionally, the ecological validity, that is the way in which a task mirrors familiar cognitive processes that individuals use in their daily lives, is an important factor for determining the suitability of a measure to a specific context.

For most who have grown-up in places like the United States or Europe, the experience of sitting quietly and answering test questions is very familiar and something that school children encounter on a regular basis. For many non-literate individuals around the world this is not the case (Tarone, 2010). In rural Côte d'Ivoire, the best measure of declarative learning appears to be the recognition of faces. The ecological validity of this task is self-evident as is the cultural validity, children may not have ever been asked to look at or remember abstract pictures or memorized a list of words, but learning the faces of friends, family, and neighbors is a very familiar activity.

The success of the Faces task demonstrates several important aspects of research in low tech environments; first, it is not the mere use of a tablet which can make tablet- based tasks unsuccessful, it is instead what a child is asked to do with the tablet that matters. Second, it may not necessarily be that children who do not regularly look at two-dimensional imagery are incapable of interpreting or encoding those images, instead it is the complexity and familiarity of those images which contribute to their ability to remember them. Third, the limitation of a forced-choice paradigm can also be overcome when the task is easy to understand and culturally valid.

Finally, while I am pleased with the success of the Faces task, I would like to make special note of the difficulty which I encountered in the pursuit of stimuli. I needed to draw from many sources in order to find a small number of experimentally appropriate images of Black faces. It seems that very little research materials are available which depict images of non-White individuals. This is a significant concern. Just as it is necessary for research to reach beyond the labs of LMICs it is vital that experimental measures and the images they use are truly representative of and applicable to everyone. There is a lot still to be done to increase inclusivity and representation in scientific research.

5.3 The Contributions of Declarative and Procedural Learning to Reading

5.3.1 The Role of Declarative Learning

According to the Declarative/Procedural Model (DPM), declarative learning supports the arbitrary mapping of form to meaning. Declarative learning can contribute to reading both in its ability to support the growth of world knowledge and aid the comprehension of meaning. It can also support reading through its support of the quick encoding of visual information, as demonstrated by the Faces task of declarative learning.

Previous work has found that visual, and not verbal declarative learning was related to vocabulary learning among adult second language learners (Ruiz et al., 2021). Yet, the visual measure of declarative learning used in this dissertation demonstrates a strong negative effect on letter reading, suggesting that visual declarative learning could adversely impact emergent reading. Further previous work has found that visual declarative learning is related to phonological awareness in adults (Arthur et al., 2021), meaning that among those with more mature declarative learning, declarative learning can take over previously procedurally supported skills. For the adolescent emergent readers in Côte d'Ivoire whose phonological awareness skills have not yet fully developed, declarative support of these skills is not able to support the progression towards skilled phonological awareness and skilled reading.

5.3.2 The Role of Procedural Learning

Similar to DPM's framework, the studies of this dissertation demonstrate that procedural learning supports the fundamental structural aspects of reading. Children with better procedural learning had a stronger relation between reading and phonological awareness and children with poorer procedural learning had a weaker relation between reading and phonological awareness, suggesting that procedural learning supports phonological awareness, an important skill for acquiring the phoneme-to-grapheme mapping. Further supporting the DPM's framework, children with poorer procedural learning had a stronger relation between reading and vocabulary, suggesting that the aspects of reading which involve the arbitrary mapping of form and meaning do not rely on procedural learning.

5.4 The Value of Replication

A recent concern in the behavioral sciences has been labeled the "Replication Crisis", that is a consistent failure to reproduce the findings of published research. A failure to replicate casts doubts not just on the original findings but on the widely accepted procedures for the collections and analysis of behavioral and cognitive data, and on the theoretical frameworks that are formed as a result of that analysis. In order to build a strong, resilient, model of emergent reading it is necessary to build up evidence that is resistant to type one error. Particularly, regarding research of underrepresented populations, for which the foundation of evidence is already at a disadvantage. It is therefore a valuable contribution to the understanding of adolescent emergent reading to produce findings that can be replicated in independent samples.

The relation between phonological awareness and procedural learning is consistent in both fifth graders and sixth graders of the same ages. The relation also appears to be consistent as reading skills progress, as the sixth-grade sample were significantly better readers than the fifth- grade sample. The replication, therefore, indicates that as children progress through their literacy education and literacy skills develop, the contributions of procedural learning remain a key to reading success.

5.5 The Impact of Age on Reading-Related Language Skill

Another valuable contribution to the understanding of adolescent literacy and language learning was the impact of age on phonological awareness and the apparent age invariance of vocabulary. Many (including the DPM) have suggested that aspects of language can be differentially affected by increasing age, specifically, during peripuberty. The structural aspects of language such as phonology and morphosyntax become more difficult to learn. Phonological awareness, as a skill which relies on an understanding of the structure of language is subject to these age-related difficulties. Further, as the DPM suggests, the findings of this dissertation demonstrate that phonological awareness is supported by procedural learning. The reduced ability to acquire phonological awareness mirrors the DPM’s proposition that procedural learning’s influence in learning declines with age. Vocabulary learning, on the other hand, does not rely on procedural learning and remains available even as learners age. The findings of this dissertation add to the body of evidence both for the role of age in reading-related language skills and for the role of procedural learning as learners age.

5.6 Evaluating the DPM in Adolescent Emergent Reading

The studies in this dissertation were among the first to evaluate the role of declarative and procedural learning in adolescent emergent readers. Under the framework of the DPM, procedural learning is crucial for learning earlier in life but, as declarative learning matures, the role of the procedural system for learning is reduced. Declarative learning, as it matures, overlaps with and competes with formally procedurally supported skill learning.

The findings of this dissertation bear out some of the predictions of the DPM. First, as previously discussed, successful phonological awareness development was supported by procedural learning. Second, the adolescents who relied on vocabulary for emergent reading were also those without strong procedural learning skills. Finally, declarative learning's competition and its detrimental effects on typically procedurally supported learning among older emergent learners.

5.7 Practical Implications of these Studies

The potential practical applications of the studies included in this dissertation can be for both science and education. The findings regarding the measures of declarative learning can hopefully provide future researchers working in contexts like Côte d'Ivoire with a reliable and valid measure. For education, the findings regarding declarative and procedural learning have implications for the importance of early access and consistent exposure to literacy education. To address the needs of older emergent readers, teachers might pursue methods which promote proceduralization and mitigate the negative impact of declarative learning, such as avoiding methods which rely heavily on memorization and instead focus on providing children with ample opportunities to practice and refine decoding skills.

5.8 Future Directions for Research

Since this dissertation represents some of the first research to examine adolescent emergent reading, it has only taken the initial steps towards a greater understanding of the needs of adolescent emergent readers. There are many questions left to explore and more evidence to gather regarding the impact of declarative learning for older children. For example, future work might clarify the relations between age of exposure, phonological awareness, and declarative learning by examining how declarative learning impacts adult emergent readers. If developing declarative learning is better at supporting emergent reading beyond early adolescents then this indicates that the negative impact of declarative learning for adolescent emergent reading is due to the development of declarative learning, that is to say their declarative learning may be mature but not mature enough. Further, a better understanding of the process of proceduralization as reading skills progress would shed light on the timing and amount of exposure necessary to successfully achieve this progress. Longitudinal studies evaluating how emergent reading proceduralizes as education progresses would provide valuable insight and further inform educational practices which address the unique challenges of learning to read in adolescence.

Additionally, as previous work has demonstrated that declarative learning supports the structural aspects of second language the role of second language skills and monolingual versus bilingual education in emergent reading should be explored further. Potentially, children who learn to read for the first time in a second language which they have acquired later in childhood face greater declarative competition. The studies included in this dissertation were not able to fully test the role of second language learning as the true age of exposure to French is difficult to determine and a low number of children in each sample reported a potential early exposure due to the presence of a French Speaking adult in their home. Finally, to further broaden the universal understanding of reading acquisition, the field should continue gathering evidence and replicating results among populations of adolescent emergent readers with complex linguistic and literacy environments like the children of Côte d'Ivoire.

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Appendix

IRB/HUMAN SUBJECTS APPROVAL

UNIVERSITY OF DELAWARE

Institutional Review Board
210H Hullihen Hall
Newark, DE 19716
Phone: 302-831-2137
Fax: 302-831-2828

DATE:	November 11, 2020
TO:	Kaja Jasinska, PhD
FROM:	University of Delaware IRB
STUDY TITLE:	[1139108-11] Neural Basis of Linguistic and Cognitive Processing and Reading in Children and Adults
SUBMISSION TYPE:	Continuing Review/Progress Report
ACTION:	APPROVED
APPROVAL DATE:	November 11, 2020
EXPIRATION DATE:	November 12, 2021
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # *(4,6,7)*

Thank you for your Continuing Review/Progress Report submission to the University of Delaware Institutional Review Board (UD IRB). The UD IRB has reviewed and APPROVED the proposed research and submitted documents via Expedited Review in compliance with the pertinent federal regulations.

As the Principal Investigator for this study, you are responsible for and agree that:

- All research must be conducted in accordance with the protocol and all other study forms as approved in this submission. Any revisions to the approved study procedures or documents must be reviewed and approved by the IRB prior to their implementation. Please use the UD amendment form to request the review of any changes to approved study procedures or documents.
- Informed consent is a process that must allow prospective participants sufficient opportunity to discuss and consider whether to participate. IRB-approved and stamped consent documents must be used when enrolling participants and a written copy shall be given to the person signing the informed consent form.
- Unanticipated problems, serious adverse events involving risk to participants, and all non-compliance issues must be reported to this office in a timely fashion according with the UD requirements for reportable events. All sponsor reporting requirements must also be followed.

Oversight of this study by the UD IRB REQUIRES the submission of a CONTINUING REVIEW seeking the renewal of this IRB approval, which will expire on November 12, 2021. A continuing review/progress report form and up-to-date copies of the protocol form and all other approved study materials must be submitted to the UD IRB at least 45 days prior to the expiration date to allow for the required IRB review of that report.

If you have any questions, please contact the UD IRB Office at (302) 831-2137 or via email at hsrb-research@udel.edu. Please include the study title and reference number in all correspondence with this office.

INSTITUTIONAL REVIEW BOARD

www.udel.edu

Institutional Review Board
210H Hullihen Hall
Newark, DE 19716
Phone: 302-831-2137
Fax: 302-831-2828

DATE:	August 19, 2021
TO:	Kaja Jasinska
FROM:	University of Delaware IRB
STUDY TITLE:	[1223553-10] Phonological Awareness by Phone to Improve Early Reading Skills in Ivory Coast
SUBMISSION TYPE:	Continuing Review/Progress Report
ACTION:	APPROVED
APPROVAL DATE:	August 19, 2021
EXPIRATION DATE:	August 19, 2022
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # *(4,7)*

Thank you for your Continuing Review/Progress Report submission to the University of Delaware Institutional Review Board (UD IRB). The UD IRB has reviewed and APPROVED the proposed research and submitted documents via Expedited Review in compliance with the pertinent federal regulations.

As the Principal Investigator for this study, you are responsible for and agree that:

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