Je voudrais parler français: Brain activity during sleep supports second language learning

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Abstract

Language learning depends on a variety of cognitive abilities, including long-term memory. Sleep is important for the enhancement of memory for newly acquired information and skills. Much of what we know about the relationship between sleep and memory has come from the investigation of two distinct long-term memory systems: declarative (memory for e.g., facts, figures and events) and procedural (memory for e.g., strategy, rules and motor skills). Several sleep-specific electrophysiological markers of memory processing have been identified. More specifically, sleep spindles (bursts of neural oscillatory activity which characterize non-rapid eye movement (NREM) sleep) may be a marker of consolidation for declarative memory (e.g., semantics, facts, figures, events), while rapid eye movements may serve as a marker for cognitive aspects (e.g., grammatical rule-learning) of procedural memory. In adults, second language acquisition (SLA) is thought to depend at first on declarative memory for grammar and linguistic rules (*i.e.*, "early SLA"), and then shifts to procedural memory as the learner gains experience (*i.e.*, "late SLA"). Given the unique roles of spindles and rapid eye movements in declarative and procedural memory consolidation, it was hypothesized that sleep spindles would correlate with language improvement during early SLA, whereas rapid eye movements would correlate with language improvement during late SLA. Eight Anglophone University students (six females, one left-handed, ages: 17-28) completed polysomnographic recordings four times throughout an intensive 6-week French course. Electrode sites W1 and W2 (Wernicke's area- left and right hemispheres) were used to extract sleep spindle data, as well as examine event-related EEG spectral power time-locked to rapid eye movements. A correlational analysis indicated a significant positive relationship between improvements in French proficiency (post-course minus

pre-course) and the change in spindle density (early minus late SLA) at electrode W1 for NREM stage 2 and SWS. A nonparametric cluster-based permutation analysis examining event-related power time-locked to REMs, indicated that there was a significant effect of SLA stage (early versus late), whereby an increase in power during late SLA was observed in the theta band. Importantly, this increase in theta power (late minus early) positively correlated with improvements in French proficiency. This follow-up study reveals an important role for sleep spindles in early SLA, and suggests that cortical theta activity during rapid eye movements is a potential marker of learning for cognitive procedural memory during late SLA.

Keywords

Memory consolidation, second language acquisition, sleep spindles, rapid eye movements, procedural memory, declarative memory, learning, theta.

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List of Abbreviations

NREM – Non-Rapid Eye Movement

REM – Rapid Eye Movement

SWS – Slow Wave Sleep

SLA – Second Language Acquisition

EEG – Electroencephalogram

PSG – Polysomnography

EOG – Electrooculogram

EMG – Electromyogram

PGO – Ponto-geniculo-occipital

LTP – Long-Term Potentiation

Preface

This dissertation is based on the experimental data collected by Dr. Joseph De Koninck, Dr. Gilles Hébert and their team in 1991. The original findings were published in a series of pioneering papers and conference proceedings. Here, this rare and valuable dataset was re-analyzed using novel methodology in order to address new, unanswered questions about the electrophysiological correlates of SLA during sleep, using techniques that were not available at the time of the original study. The overall goal of this thesis was to follow-up the previously published series of studies, to examine how proposed markers of sleep-related memory consolidation, including sleep spindles during NREM sleep and rapid eye movements during REM sleep may relate to different stages (e.g., early vs. late) of acquiring a second language that depend on dissociable memory systems (e.g., declarative vs. procedural). Chapter One provides a general introduction into the topic areas of interest to this thesis. It begins with a description of the functions of sleep and the different sleep stages, then discusses long-term memory systems. This is followed with a discussion of how the long-term memory systems have been proposed as the domain-general mechanisms that support language acquisition; in particular the Declarative-Procedural model of language acquisition is highlighted. An overview is given of the role of sleep in the different memory systems, as well as in SLA. Chapter Two summarizes the rationale for the study as well as proposes the study hypotheses. Chapter Three describes the methodology that was used in the current data including information about the participants, the intensive second language course, the statistical analysis plan, and the procedure. Chapter Four discusses the results of the study including for behavioural and electrophysiological data. Lastly, Chapter Five

discusses the findings and provides a potential interpretation of the results, as well as highlights the limitations of the current study.

Chapter 1: Introduction

1.1. The Study of Sleep.

We spend approximately 1/3 of our lives asleep, yet the reasons why we sleep remain enigmatic. The following section begins by discussing potential answers to the question "why do we sleep?", this is followed by an overview of the measurement of sleep, and of the distinct sleep stages that comprise the NREM-REM sleep cycle. Lastly, an account is given of how sleep is regulated.

1.1.1 Theories of the Function of Sleep.

Despite decades of research on why animals require sleep as well as significant advancement on the unique physiological processes that characterize sleep, there is still no consensus on the primary function of sleep (Krueger, Frank, Wisor, & Roy, 2016). To date, there is no evidence of any animal species that does not exhibit a sleep-wake cycle (for a review, see Cirelli & Tononi, 2008), suggesting that sleep serves a crucial benefit for the survival of all organisms that have a nervous system.

In vertebrates, it has been suggested that sleep supports functions for the body including: the conservation of energy (Berger & Phillips, 1995); restoration and tissue growth (Adam & Oswald, 1977; Oswald, 1980); thermoregulation (Mcginty & Szymusiak, 1990); and immune function (Besedovsky et al., 2012; Imeri & Opp, 2009; Krueger, Walter & Levin, 1985). However, these functions could be accomplished with a simple period of rest and do not necessitate the unconsciousness that defines sleep (Rasch & Born, 2013). Thus, sleep is perplexing in that a regular state of unconsciousness appears counter to survival, as an

animal is unable to eat, drink, reproduce, and is vulnerable to predation in such a state. Therefore the benefits that accompany this prolonged state of diurnal unconsciousness must outweigh the costs, suggesting that perhaps sleep has a critical function related to the brain (Hobson, 2005; Kavanau, 1997; Krueger et al., 2016). In brief, the proposed functions of sleep for the brain include: removal of toxins and free radicals (Inoué et al., 1995; Reimund, 1994; Xie et al., 2013) synaptic homeostasis (Tononi & Cirelli, 2006), neuronal development (Li et al., 2017; Wolfe & Ralls, 2019), synaptic plasticity (Destexhe & Sejnowski, 2001; Rosanova & Ulrich, 2005) and memory and learning (for a review, see Diekelmann & Born, 2010; Rasch & Born, 2013).

1.1.2 The Measurement of Sleep.

Loomis first observed and described the different sleep stages across the night based on electroencephalographic (EEG) recordings (Loomis et al., 1937). This was followed by Aserinsky and Kleitman, who described rapid eye movement (REM) sleep (1953) in humans and concomitantly "*sommeil paradoxal*" by Michel Jouvet in cats (Jouvet et al., 1959). Lastly, Dement and Kleitman (1957) classified the cyclic pattern of non-REM (NREM) and REM sleep. Currently, the gold standard for classifying sleep stages is polysomnography (PSG), which consists of at a minimum, a combination of EEG, electrooculogram (EOG), and electromyogram (EMG; Rechtschaffen & Kales, 1968). PSG is typically scored in 30-second sequential epochs, with each epoch assigned a wake or sleep stage score (NREM or REM). NREM sleep has three subdivisions: NREM stage 1 (NREM1); NREM stage 2 (NREM2); and NREM stage 3 (NREM3; previously subdivided into NREM3 and NREM4) also known as slow wave sleep (SWS; Iber et al., 2007).

1.1.3 Sleep Stages.

While asleep, the typical adult will experience a total of four to five cycles of NREM to REM, with this cycle repeating every 90 minutes (Iber et al., 2007). The first half of the night is SWS dominant, while the second half is dominated by REM sleep. In total, a night of sleep is made up of about 5% NREM1, 50% NREM2, 15-25% NREM3 or SWS, and 20-25%% REM sleep (Carskadon & Dement, 2011).

a) Wake

Stage wake can range from an individual being fully alert and aware to drowsy. When an individual's eyes are closed, the EEG will display a tonic alpha rhythm (8-13 Hz over the occipital region theorized to represent suppression of visual information; Toscani et al., 2010), however, approximately 10% of adults do not clearly generate an alpha rhythm, and 10% generate a limited alpha rhythm (Iber et al., 2007). With eyes open, the EEG of a healthy adult will exhibit low amplitude beta activity (12.5-30 Hz) and non-synchronized alpha activity. During wake, the EOG may exhibit eye blinks at a frequency of 0.5-2 Hz, saccades, or irregular eye movements and the EMG will exhibit normal to high chin muscle tone (Iber et al., 2007).

b) NREM1

NREM1 sleep is the lightest stage of sleep and represents the transition from wake to sleep. During NREM1, the EEG will display an attenuation of the alpha rhythm which is replaced by low amplitude, mixed frequency EEG activity (4-7 Hz activity; Iber et al., 2007). Background EEG frequencies slow by >1 Hz and vertex sharp waves (sharply contoured waves that last for less than 0.5 seconds, with a maximal amplitude at central regions) appear. The EOG will exhibit slow rolling eye movements in the early stages of NREM1 and the EMG amplitude is reduced from wake (Iber et al., 2007).

c) NREM2

The beginning of NREM2 sleep is marked with the appearance of K-complexes and sleep spindles in the EEG (Iber et al., 2007). In addition, NREM2 will display less desynchronized EEG than wake, with some phasic delta waves (1-4 Hz). Typically, there are no eye movements seen on the EOG during NREM2, and the EMG is of variable amplitude, but is usually lower than in NREM1 and wake (Iber et al., 2007).

K-complexes appear on the EEG as a high amplitude (>100 μV) negative deflection, immediately followed by a positive deflection (around 350-550 ms), ending with another negative deflection (at 900 ms; Davis et al., 1939; Rechtschaffen & Kales, 1968). K-complexes have maximum amplitude over anterior and superior frontal areas (Roth et al., 1956; Wennberg, 2010) and can occur either in response to external auditory events (evoked K-complexes), or naturally (spontaneous K-complexes; Roth et al., 1956). There are two prevailing hypotheses of the function of K-complexes: 1) K-complexes reflect an arousal response (Forget et al., 2011; Roth et al., 1956), as they are associated with increased heart rate and blood pressure (Hornyak et al., 1991; Takigawa et al., 1980), number of body movements (Roth et al., 1956; Sassin & Johnson, 1968), respiration changes (Roth et al., 1956; Takigawa et al., 1980), and teeth grinding (Satoh & Harada, 1973), and, 2) K-complexes represent a sleep-protecting function (Forget et al., 2011) serving to lessen the impact of intrusive arousals (Walter, 1953), as K-complexes increase following a night of fragmented sleep (Nicholas et al., 2002), and evoked K-complexes are thought to lessen the chance of an arousal (Bastien et al., 2000). The likelihood of eliciting an evoked K-complex depends on both the physical properties of the stimuli used (i.e., the abruptness, intensity,

and presentation rate) as well as circadian influences, and can provide insight into the nature of information processing during sleep (see Campbell, 2010).

Sleep spindles occur as short distinct bursts (~0.5 seconds) in the 11-16 Hz frequency range most prominent at central derivations (Iber et al., 2007). Spindles are generated from a reduction in activating input from the brainstem reticular formation, which triggers repeating spike-bursts from GABAergic thalamic reticular neurons that then generates an inhibitory post-synaptic potential in glutamatergic thalamocortical neurons (De Gennaro & Ferrara, 2003; Dijk et al., 1993; Steriade, 1999). Sleep spindles serve a cognitive function, as they have been associated with intellectual abilities (Bódizs et al., 2005; see Fogel & Smith, 2011; Nader & Smith, 2001), aptitude (see Fogel & Smith, 2011; Gais et al., 2002; see Rasch & Born, 2013), reasoning (Fang et al., 2019), efficient cortical-subcortical connectivity (Schabus et al., 2006), cognitive flexibility (Schabus et al., 2006), optimizing consolidation of memory for both motor skills and facts (Fogel & Smith, 2006; Gais et al., 2002; Schabus et al., 2006; Schabus et al., 2004), and may represent a mechanism for long-term synaptic changes (Destexhe & Sejnowski, 2001; Rosanova & Ulrich, 2005). Spindles have also been proposed to have sleep-protecting functions, as they serve to shield against awakening from auditory stimulation (Dang-Vu et al., 2011; Schabus et al., 2012; Wimmer et al., 2012).

One of the underlying rhythms which coordinates the typical features of NREM sleep such as K-complexes and spindles is the slow oscillation. The slow oscillation contains a depolarizing phase, consisting of synaptic events, and the firing of action potentials (up state), followed by a hyperpolarization phase, consisting of few synaptic events, and no activity spikes (down state) (Cowan & Wilson, 1994; Steriade, McCormick, et al., 1993;

Steriade, Nunez, et al., 1993). Functionally, slow oscillations are generated in the neocortex (Sanchez-Vives & McCormick, 2000; Timofeev et al., 2000), and are associated with memory consolidation (Marshall et al., 2006; Mölle et al., 2004, 2006; Sirota & Buzsaki, 2005; Steriade & Timofeev, 2003) with the more information encoded during wake resulting in higher amplitude oscillations (Huber et al., 2004; Mölle et al., 2004).

d) NREM3 or SWS

In SWS, the EEG is characterized by tonic large amplitude slow/delta waves (1-4 Hz, 75 – 140 μV), as well as the presence of sleep spindles and K-complexes (Iber et al., 2007). Typically, there are no eye movements seen on the EOG during SWS, and the EMG is usually lower than or similar to NREM2 (Iber et al., 2007).

SWS is homeostatically regulated (Borbély & Achermann, 1999; Dijk & Czeisler, 1995; Webb & Agnew, 1971), with SWS deprivation resulting in increased sleep pressure and SWS rebound (Dijk et al., 1987). SWS is thought of as a restorative sleep stage associated with sleep quality (Åkerstedt et al., 1997), sleep maintenance (Dijk et al., 2006), release of growth hormone (Sassin et al., 1969), and an autonomic nervous system switch from sympathetic to parasympathetic dominance (Brandenberger et al., 2001; Viola et al., 2008).

e) REM Sleep

REM sleep was discovered by Aserinsky & Kleitman (1953) and is so named because of the appearance of conjugate, irregular, sharply peaked eye movements lasting less than 500 ms (Iber et al., 2007). REM sleep is also known as paradoxical sleep (Jouvet et al., 1959) due to its similar appearance to the low amplitude, mixed frequency EEG of wake; however in REM, it is accompanied by muscle atonia which results in low chin muscle tone (Iber et al., 2007). “Sawtooth waves”, which appear as sharply contoured serrated 2-6 Hz waves with maximal amplitude at central regions, may also be present during REM sleep (Iber et

al., 2007). In humans, theta waves occur during REM sleep observed in the hippocampus (Cantero et al., 2003) and neocortex (Cape et al., 2000; Nishida et al., 2008), but are not synchronized between the two (Axmacher et al., 2008; Cantero et al., 2003). Theta waves may play an important role in the formation of long-term memories (Hölscher et al., 1997; Huerta & Lisman, 1996; Larson & Lynch, 1986; Pavlides et al., 1988). Functionally, REM sleep has been associated with memory consolidation (Dement, 1965; Fishbein & Gutwein, 1977; Meienberg, 1977; Smith & Lapp, 1991) including the stabilization of new memories (Hopfield et al., 1983), reactivation of emotional events (for a review, see Vandekerckhove & Cluydts, 2010), development of neural circuits (Blumberg et al., 2013), improvement of signal-to-noise ratios in neural networks (Crick & Mitchison, 1983; Poe, 2017; Sara, 2017), and dreaming (see Hobson et al., 1999; De Koninck, 2012).

Ponto-geniculo-occipital (PGO) waves are present in REM sleep for certain species of animals (see Gott et al., 2017) and are recorded as biphasic sharp field potentials observed within the pons (Jouvet et al., 1959), lateral geniculate bodies (Mikiten et al., 1961), and occipital cortex (Mouret et al., 1963). A link between PGO and the generation of eye movements has been observed (Brooks, 1968; Datta & Hobson, 1994). PGO waves are also characteristic in human REM sleep (Lim et al., 2007; McCarley et al., 1983) and are associated with the generation of eye movements during REM (Peigneux et al., 2001). Other studies suggests that sharply contoured theta waves may serve as the human correlate of PGO waves (Frauscher et al., 2018). Interestingly, the eye movements during REM sleep are associated with memory consolidation (Herman & Roffwarg, 1983; Mandai et al., 1989; Smith & Weeden, 1990; Verschoor & Holdstock, 1984), however, given the role of PGO

waves in generating eye movements, this may be an indirect test of the functional significance of PGO waves (see Datta, 1999) or some other underlying activity.

1.1.4 Sleep Regulation.

Sleep propensity and duration are presumed to be determined by the combination of two processes: Process S, which accumulates in a logarithmic way with time awake and dissipates exponentially with sleep; and Process C, a sinusoidal rhythm dependent on circadian processes (Borbély, 1982). While the level of Process S is dependent on prior waking time (indicated by increasing slow wave activity (SWA) in sleep EEG; Achermann et al., 1993; Borbély et al., 2016), Process C is a rhythmic variation (indicated by melatonin release, and core body temperature changes; Borbély et al., 2016; Borbély & Achermann, 1999) presumably controlled by a circadian pacemaker. The brain structure proposed to be the circadian master clock is the suprachiasmatic nucleus, which has been shown to be important for regulating core body temperature, metabolic activity, arousal, and wake propensity (Borbély et al., 2016; Saper et al., 2010). As a result of these two processes, the onset of sleep occurs when sleep pressure reaches its upper bound, and circadian arousal (which is highest in the early evening, and decreases by mid to late evening) declines (Borbély, 1982).

1.2 Memory systems.

Prominent theories of second language acquisition suggest that the acquisition of a novel language requires participation from long-term memory systems (*i.e.*, see Ullman, 2001a, 2001b, 2001c, 2004). In order to discuss these ideas further, an overview of long-term memory is first reviewed, which is followed by a discussion of the different long-term memory systems.

1.2.1 Long-term Memory.

Memory formation occurs in three phases: 1) Encoding: the perception of information forms a new memory trace (see Rasch & Born, 2013), 2) Consolidation: a labile memory trace is integrated into existing memory networks and transformed into a more permanent store (consolidation hypothesis first proposed by Müller & Pilzecker, 1900), and, 3) Retrieval: the now stabilized, integrated and more accessible memory is accessed and recalled (Melton, 1963; see Rasch & Born, 2013). During retrieval, the process of reconsolidation also takes place due to the destabilization and manipulation of the memory trace (Walker et al., 2003).While wake is considered to be the ideal state for encoding and retrieval, sleep has been proposed as optimal for consolidation (Born & Wilhelm, 2012; Rasch & Born, 2013). As consolidation and encoding have been suggested to use similar neuronal and cognitive resources, sleep may provide the optimal conditions for consolidation due to reduced external information processing (Rasch & Born, 2013). This is thought to be one of the primary reasons that unconsciousness is required for sleep.

Early experiments showed that repetitive activation of excitatory synapses located in the hippocampus caused increases in synaptic strength that lasted over time (Lomo, 1966). This has come to be known as long-term potentiation (LTP). LTP is thought to underlie memory formation (for a review, see Lynch, 2004). For example, LTP is an integral process in brain regions such as the hippocampus in order to support learning and memory processes (Malenka & Nicoll, 1999). Bursts of activity that induce LTP mimic the theta rhythm observed in the hippocampus during learning (Diamond et al., 1988; Greenstein et al., 1988; Larson et al., 1986; Rose & Dunwiddie, 1986). Lastly, inhibiting LTP blocks hippocampal learning and memory retention (Morris et al., 1986). Long-term potentiation is associated

with the encoding phase of memory formation and leads to synaptic and systems consolidation (Dudai, 1996, 2004). Synaptic consolidation occurs within the first few hours of encoding and results in changes of the synaptic connections that contribute to a memory representation (Kandel, 2001; Redondo & Morris, 2011). System consolidation lasts for longer (from hours to years) and involves a reorganization of the memory representation (how a memory trace is distributed across the brain) for long-term storage (Frankland & Bontempi, 2005).

1.2.2 Memory Types.

The distinction between different types of long-term memory has been a subject of debate throughout the history of memory research. One of the first written records of such a dichotomy comes from William James (1890) who distinguished between memory (recall of past experiences and facts) and habits (learning that simplifies the required movement to achieve a result). This was followed by Bergson (1910) who differentiated a memory for our past (a recollection), and a non-representational memory (a bodily habit). Furthermore, these distinctions have also been made by McDougall (1923), Tolman (1948), Ryle (1949), and Bruner (1969). The similarities between these previous ideas about the different types of memory, is a division based on functional differences (Cohen et al., 1985; Cohen & Squire, 1980; Squire & Zola-Morgan, 1988) for knowing what (declarative; also known as explicit memory) compared with knowing how (procedural; also known as implicit memory). Declarative memory is described as the conscious long-term memory for facts and events that are encoded intentionally, or unintentionally, but can be recalled with awareness of the memory. Procedural memory is described as memory for performing different actions or

learning new skills, which does not require active recollection, and is usually acquired without conscious knowledge.

1.2.3 Declarative Memory.

Declarative memory is subdivided into: 1) episodic memory for autobiographical events that are embedded in a spatiotemporal context involving "mental time-travel" (Tulving, 1983), and, 2) semantic memory for facts that are stored independent of the context and personal experience in which they were encoded (Squire & Zola, 1996; Tulving, 1985; Tulving, 1985). However, semantic memories are not entirely independent from episodic memory, as we learn new concepts and facts from our experiences. One role proposed for the declarative memory system in language learning is encoding word meanings and sounds (Ullman, 2001a, 2001b, 2001c, 2004). In line with this, classic tasks that are used to asses semantic declarative memory skills tap into processes involved in language learning. For example, the Rey Auditory Verbal Learning Test (Schmidt, 1996), and the California Verbal Learning Test (Delis et al., 1987) both evaluate verbal response inhibition, retention, encoding, and retrieval through learning lists of words. Furthermore, the word-paired associates task (a form of paired associate learning, developed by Mary Whiton Calkins, 1894), has subjects memorize pairs of words and then recall one of the associated pairs from memory. These task demands are analogous to the process of learning new words, as a novel word is typically paired with the concept in the native language.

An influential two-stage model of memory consolidation for declarative memory was proposed by Marr and colleagues (1991). In line with the standard model of systems consolidation of declarative memory (Squire & Alvarez, 1995), this model states that initially, memories are processed in a fast learning store located in the hippocampus, and

then transferred to the neocortex for long-term storage. This model explains why declarative memory can often be encoded quickly, as memory is initially processed in this fast learning store (for a review, see Rasch & Born, 2013). Evidence that the hippocampus has a time-limited role in creating new declarative memories has been supported through neuropsychological studies of brain damaged individuals. It has been found that damage to the hippocampus in humans produces amnesia preferentially affecting recent declarative memories but not remote ones (Beatty et al., 1987; Rempel-Clower et al., 1996; Salmon et al., 1988; Squire et al., 1975). Along with the hippocampus, other key structures that support declarative memory include the entorhinal, perihinal, and parahippocampal cortices (Davachi, 2006; Squire et al., 2004; Squire & Zola-Morgan, 1991; Staresina et al., 2011).

1.2.4 Procedural Memory.

Generally, procedural memory involves frontal/basal ganglia circuits, accompanied by the parietal cortex, superior temporal cortex, and the cerebellum (*i.e.*, see Heilman et al., 1997; Mishkin et al., 1984; Schacter & Tulving, 1994; Squire & Zola, 1996; Ullman, 2001c, 2004). Procedural memory can be further differentiated based on cognitive complexity into the motor skills and the cognitive skills needed to complete the task (Smith, 2001; Smith et al., 2004; Smith, 1995). Motor skills include memory for cognitively simple motor movements, where a series of movements is memorized and repeated. Cognitive skills encompass cognitively complex activities, involving the acquisition and use of implicit cognitive strategies as well as the use of problem solving. Whereas motor skills improve with practice, cognitive skills only improve after acquiring a rule or strategy.

a) Motor Skills.

Motor skill learning has been assessed using tasks such as: the pursuit rotor task (Adams, 1952; Ammons, 1955), and the sequential finger-tapping task (Karni et al., 1995). These tasks are considered cognitively simple in that they assess straightforward motor movements, such as eye-hand coordination, or the integration of a sequence of movements into a unit. As language learning involves cognitively complex procedural memory, a detailed discussion of motor skill learning is not covered here.

b) Cognitive and grammatical skills.

Cognitive skill learning involves either acquiring a cognitive strategy, problem solving or rule-based (i.e., grammatical) learning. The artificial-grammar task (Cleeremans & McClelland, 1991; Fischer et al., 2006), the Tower of Hanoi (invented by Édouard Lucas in 1883), the mirror tracing task (Starch, 1910), the corsi block test (Corsi, 1973) and the Wff'n proof task (Allen, 1966) are classic examples of procedural tasks thought to be cognitively complex in nature. Critically, these tasks involve acquiring and utilizing an implicit rule, a task that is critical for language learning and the acquisition of new grammatical rules. Evidence from neuroimaging and neuropsychological studies implicate the prefrontal cortex, hippocampus, anterior cingulate cortex, and the striatum (particularly, the caudate) in the cognitive skill learning involved in these types of tasks (Baker et al., 1996; Morris et al., 1993; Owen et al., 1996, 1998; Poldrack et al., 1999; Saint-cyr et al., 1988; Xu & Corkin, 2001).

Learning complex procedures such as the Tower of Hanoi have been evaluated in the context of the Adaptive Control of Thoughts model and Fitts' model of skill acquisition (ACT; Anderson, 1999; Beaunieux et al., 2006; Fitts, 1954). Here, it is proposed that cognitive procedural learning occurs in three phases: cognitive, associative, and

autonomous. In the cognitive phase, procedures are highly controlled and involve a combination of strategies based on declarative memory skills, working memory, executive functioning, and general intelligence. This phase is associated with activation in the prefrontal cortex, cerebellum, and parietal regions (Hubert et al., 2007). When learning transitions to the associative phase, the procedure becomes more automatic, and still similarly involves problem solving and working memory to generate new cognitive procedures but to a lesser extent, compared with the cognitive phase. Here, activations in the occipital regions, right thalamus, and the caudate nucleus are observed (Hubert et al., 2007). Finally, in the autonomous phase, the task no longer requires the same amount of conscious cognitive effort, and is considered to be solely reliant on procedural memory. Activations are observed during this phase in the left thalamus and the anterior part of the cerebellum (Hubert et al., 2007). This view of procedural learning, importantly, contends that procedural memory is initially in part, the product of a declarative memory representation, for which there is complimentary support in other procedural domains (i.e., motor sequence acquisition; Albouy et al., 2013).

1.3 Language.

The following section begins by discussing the general study of language, this is followed by an account of how the first language is acquired, which is then contrasted with a discussion of how a second language is acquired. Lastly, the idea of hemispheric lateralization during SLA is considered.

1.3.1 Linguistics.

Linguistics is the study of language and how we perceive, produce, and employ words in order to communicate. Specifically, linguistics is concerned with the various aspects of

language including semantics (how language is used to produce meaning), pragmatics (how context contributes to meaning), phonetics (physical aspects of word sounds), the mental lexicon (the mental dictionary), syntax (sentence structure), morphology (the study of word forms), and grammar (the whole system of language structure – including syntax and morphology) (for a review see, Miller, 2004).

1.3.2 Language Acquisition.

A long-standing debate within the cognitive study of language is whether the language domain is maintained by domain-specific mechanisms that evolved to support language acquisition (a specialized language system), or whether domain-general mechanisms adapted to support language acquisition (pre-existing cognitive systems that support learning on a broad level; for a review see, Hamrick et al., 2018). The latter idea of domain generality is supported by the findings that neural areas that maintain declarative and procedural memory also support linguistic processes (for a review see, Ullman, 2001c). In the present thesis, a focus is placed on domain general accounts of language acquisition with an emphasis on long-term memory systems. The involvement of declarative and procedural memory systems in language learning is described in Ullman's Declarative-Procedural Model of language acquisition (Ullman et al., 1997; Ullman, 2001b, 2001a, 2001c, 2004).

According to the Declarative-Procedural model, when a child acquires their first language, the process of learning lexical items (including the sound and meaning of words) requires the declarative memory system while learning grammar and rule-based combinations relies on the procedural memory system (Ullman et al., 1997; Ullman, 2001b, 2001a, 2001c, 2004). These systems interact so that while a child is learning word forms in declarative memory, they are also gradually acquiring grammar and rule-based syntax. This

model suggests that lexical and grammatical items are functionally distinct and subserved by different memory systems and associated neural areas. Neuropsychological studies support this notion (*i.e.*, for a review see the following: Alzheimer's disease: Ullman, 2005; Ullman et al., 1997; Aphasia: Ullman, 2005; Huntington's disease: Teichmann et al., 2006; Teichmann, Dupoux, et al., 2008; Teichmann, Gaura, et al., 2008; Parkinson's disease: Ullman et al., 1997; and language impairment: Ullman & Pierpont, 2005). For example, in Alzheimer's disease, patients are severely impaired at learning and remembering facts, events, and words (Corkin, 1982; Nebes, 1989; Sagar et al., 1988), but have spared procedural memory skills (Beatty et al., 1994; Gabrieli et al., 1993; Saint-Cyr et al., 1988) with unimpaired grammar processing (Irigaray, 1973; Nebes, 1989; Schwartz et al., 1979). Likewise, those with Parkinson's Disease have degeneration in the basal ganglia, and show impairments in procedural memory skills (Bondi & Kaszniak, 1991; Harrington & Haaland, 1991; Heindel et al., 1989; Saint-Cyr et al., 1988), which results in trouble understanding sentences (Grossman et al., 1992; Lieberman et al., 1992), and the production of syntactically simple speech (Illes, 1989).

1.3.3 Second Language Acquisition.

Generally, people who learned a second language later in life do not reach the same level of proficiency that is obtainable by those who learned a second language early in life (Birdsong, 1999; Johnson & Newport, 1989; Newport, 1990). This difference appears to be a result of difficulty in the acquisition and processing of grammar (Coppieters, 1987; DeKeyser, 2005; Johnson & Newport, 1989), whereas the ability to acquire lexical information (Eubank & Gregg, 1999) and lexical-conceptual processing (Hahne & Friederici, 2001; Weber-Fox & Neville, 1996) remains unaltered. However, in some cases,

with enough experience, a native-like understanding of a late-learned second language is still possible (Birdsong, 1992).

A different set of predictions is made by Ullman's declarative-procedural model for adult second language learners (Ullman, 2005; Ullman, 2001c, 2004), whereby, Ullman predicts that there would be more difficulty acquiring grammar using the procedural memory system. This could result from changes in memory systems across the lifespan, including: (1) working memory, (2) procedural memory, and (3) declarative memory. For example, (1) the ability for rule-abstraction decreases across the lifespan due to changes in working memory capacity (Newport, 1990), and a decline begins in early adulthood for processing-intensive tasks (*i.e.*, processing speed, working memory, and long-term memory; Park et al., 2002). (2) While there is debate on the exact trajectory of procedural memory across the lifespan, it is generally accepted that there are age-related changes in procedural learning (see Zwart et al., 2019). For example, two models that have received support suggest that either there is a peak in performance during young adulthood followed by a gradual decline (Thomas et al., 2004), or there is a plateau in childhood followed by a gradual decline (Janacsek et al., 2012). Both of these models contend that the capabilities of the procedural system have declined by adulthood. Lastly, (3) given the proposed interaction between the two memory systems, a general enhancement for the declarative memory system in adulthood could attenuate the reliance on procedural learning abilities (which is observed in first language acquisition for children). This is supported by findings that adults have greater declarative memory capacity than children (Finn et al., 2016), and the declarative memory system is still developing during childhood (Campbell & Spear, 1972; Digiulio et al., 1994;

Kail & Hagen, 1977; Meudell, 1983; Siegler, 1978), which may prevent it from attenuating the use of the procedural memory system.

Ullman's Declarative-Procedural model (Ullman, 2005; Ullman, 2001c, 2004) suggests that adult second language learners initially rely on the declarative memory system for both lexical information (including word meanings and sounds), and the acquisition and use of grammar. Word forms that are computed compositionally in the first language are memorized in the second language (*i.e.*, see Deng et al., 2016; Kimppa et al., 2019). For example, a beginner learner (*i.e.,* Early SLA) may memorize that the past tense of the English word *walk* is *walked*. This would result in a limitation in the level of proficiency that is achievable for the second language. However, based on studies proposing that practice in implicit learning leads to improved performance (Mishkin et al., 1984; Schacter & Tulving, 1994; Squire & Zola, 1996; Squire & Knowlton, 2000), Ullman (2001c, 2004, 2005) suggests that as proficiency in the second language improves (*i.e.*, Late SLA), grammar becomes increasingly dependent on the procedural memory system (i.e., the use of heuristic rules). For example, an experienced learner may recognize that the English word *walk* is a regular verb, and knowing that regular verbs are conjugated with *–ed* to denote past tense, they would compute the past tense of *walk* as *walked*.

Ullman's Declarative-Procedural model of SLA (2001c, 2004, 2005) has received support based on observed differences between beginner and advanced second language learners. Beginner second language learners, or those with low morphological knowledge are suggested to rely on whole word level processing, whereas those who are advanced, or who have high morphological knowledge show word-parsing, including decomposing and identifying morphological violations (Deng et al., 2016; Kimppa et al., 2019). This supports

the idea that those with experience in the second language shift toward the procedural memory system and are able to apply rule-based grammar, while those who are inexperienced rely more on the declarative memory system by memorizing whole word forms. Furthermore, individual differences in procedural and declarative memory are predictive of SLA (Brill-Schuetz & Morgan-Short, 2014; Granena, 2013; Hamrick et al., 2018; Morgan-Short et al., 2014, 2015). Behavioural measures of declarative memory predict early grammar learning, while behavioural measures of procedural learning predict late grammar learning (Morgan-Short et al., 2014). When training in an artificial language occurs in an immersion-like context, high procedural memory ability is associated with better performance at the later stages of learning (Brill-Schuetz & Morgan-Short, 2014). Sequence learning ability (a procedural memory task) has also been shown to moderate grammatical sensitivity in late second language learners (Granena, 2013).

1.3.4 Hemispheric Lateralization during SLA.

There is an abundance of research to suggest that the first language is represented in the brain as left-lateralized (see Ocklenburg et al., 2014), while the relationship for the second language is more complex. The *second language hypothesis* predicted that bilinguals in general have more right hemisphere lateralization compared with monolinguals (Fred Genesee, 1982). However, this relationship does not appear as clear cut. Inconsistent findings (*i.e., no laterality differences between bilinguals and monolinguals*: Galloway & Scarcella, 1982; Hynd & Scott, 1980; Soares, 1982, 1984; *greater left lateralization for bilinguals*: McKeever & Hunt, 1984; Vaid, 1987; *greater right hemisphere activation for bilinguals*: Scott et al., 1979; Vocate, 1984) have led researchers to investigate potential

moderators for this relationship including: the age of acquisition, proficiency level, and manner of SLA.

The age hypothesis (Genesee et al., 1978; Vaid & Genesee, 1980; see Vaid, 1983) predicts that if the second language is acquired close to when the first language was acquired then it will show a similar left-lateralization pattern, whereas late-learned second languages will show greater right hemisphere participation. While this relationship has received some support (Albert & Obler, 1978; Chary, 1986; Rogers et al., 1977; Scott et al., 1979; Vocate, 1984), the opposite relationship has also been found, suggesting that there is greater left hemisphere participation for those who acquired the second language late, but equal left and right activations for those who acquired the second language early (Gordon, 1980).

The *balanced bilingual* hypothesis, suggests that proficient bilinguals show less left hemispheric lateralization for both their first and second language compared with monolinguals (Galloway, 1983), while the *stage hypothesis* (Albert & Obler, 1978; Galloway & Krashen, 1980; Obler, 1981; Schneiderman, 1986; Vaid, 1983) predicts that experts will experience a shift in the language representation from the right hemisphere to the left as syntax and phonological production rules are automatized. Again, however, there appears to be disagreement as some findings support this prediction (Silverberg et al., 1979); while others do not (Galloway & Scarcella, 1982; Gordon, 1980).

Lastly the *manner of L2 acquisition hypothesis*, suggests that for late-learned second languages there will be greater right-hemisphere involvement if it is acquired informally (*i.e., naturalistic setting*), compared with acquisition in a formal setting (*i.e., classes*; Galloway & Krashen, 1980; Krashen & Galloway, 1978).

The appearance of conflicting results between studies on bilingual lateralization has been suggested to occur due to task differences in the assessments used. For example, studies vary in: the level of processing, whether the task involves perception or production; if two languages are presented within the same stimulus set; memory constraints; what dependent measure is used (*i.e.,* accuracy, reaction time, errors or order of report), practice effects; and the control group used (see Obler et al., 1982). While most studies examine lateralization during behavioural language tasks, perhaps examining lateralization during memory consolidation while participants acquire a second language may provide the opportunity to eliminate methodological confounds related to task differences while also providing evidence in the second language lateralization debate.

1.4 The Role of Sleep in Memory.

Several theories have been suggested to explain the role of sleep in learning and memory, and there is now a wealth of knowledge on this topic (for a review see, Rasch & Born, 2013). Briefly, sleep has been suggested to (1) play a passive role, protecting the memory trace against retroactive interference (Jenkins & Dallenbach, 1924). (2) Sleep has been associated with the erasure and filtering of information (Clark et al., 1985; Crick & Mitchison, 1983; Evans & Newman, 1964; Feinberg & Eyarts, 1969). (3) Sleep is suggested to consolidate different types of memory via the different sleep stages (Dual Process hypothesis; Peigneux et al., 2015; Gais & Born, 2004; Maquet, 2001; Rauchs et al., 2005; Smith, 2001a). (4) Sleep is suggested to play a critical role in memory formation with each stage of sleep in the NREM to REM sleep cycle, playing a complementary role (Sequential hypothesis; Ambrosini et al., 1992; Giuditta, 1985; Giuditta et al., 1995; Langella et al., 1992). (5) Lastly, sleep is suggested to consolidate learning and memory via a combination

of the Sequential and the Dual Process hypotheses whereby, memory consolidation during sleep is the product of reactivation of new memory representations during sleep (Active System Consolidation hypothesis; Diekelmann & Born, 2010; Oudiette & Paller, 2013). The following section is an account of the different roles proposed for sleep stages in declarative and procedural memory consolidation and how this literature may be important for our understanding of SLA. This is followed by a description of the research that shows a link between sleep and language acquisition.

1.4.1 The role of sleep in declarative memory consolidation.

Studies of declarative memory consolidation have examined the retention of verbal information such as memorizing word-pairs (i.e., verbal paired associates task), word-lists (rote learning), or story passages. As similar processes are involved in beginner second language learning (Ullman, 2005; Ullman, 2001c, 2004), research on declarative memory consolidation is important for understanding how language may be consolidated during the early phase of SLA. Generally, declarative memory consolidation has been associated with NREM sleep (Fowler et al., 1973; Gais et al., 2000; Maquet, 2001; Plihal & Born, 1997; Carlyle Smith, 1995; Yaroush et al., 1971). For example, declarative memory is enhanced following daytime-naps that are rich in NREM sleep (Ruch et al., 2012; Schmidt et al., 2006; Tucker et al., 2006; Tucker & Fishbein, 2008). Using the night-half paradigm, which deprives participants selectively of either early (SWS dominant) or late (REM dominant) sleep (Yaroush et al., 1971), a beneficial role of early sleep on word-pair declarative learning has been found (Fowler et al., 1973; Plihal & Born, 1997; Yaroush et al., 1971) independent of circadian influences (Barrett & Ekstrand, 1972). Slow wave activity during SWS and sleep spindles during NREM sleep have both been proposed as specific

mechanisms in NREM sleep that support declarative learning and memory consolidation (see Section 1.4.1.1, 1.4.1.2 for more details). The implications of this include the prediction that during Early SLA, when declarative memory is important, sleep spindles or slow wave activity may be instrumental in the consolidation of language learning.

1.4.1.1 Sleep Spindles.

Sleep spindle activity during NREM2 and SWS is correlated with overnight retention in declarative memory (*i.e.*, ***NREM2*:** Gais et al., 2002b; Genzel et al., 2009; Ruch et al., 2012; Schabus et al., 2004, 2008; Schmidt et al., 2006; ***SWS*:** Berner et al., 2006; Cox et al., 2012; ***Whole NREM period*** Clemens et al., 2005; Genzel et al., 2009; Saletin et al., 2011). Briefly, sleep spindles during NREM sleep appear important for consolidation during verbal declarative memory tasks, for example, overnight verbal memory retention is correlated with the number of spindles over left frontocentral areas (Clemens et al., 2005). Furthermore, sleep spindle density increases after learning word-pairs, and correlates with recall performance before and after sleep, independent of individual learning traits (Gais et al., 2002b; Schabus et al., 2008; Schabus et al., 2004). Encoding more difficult words (*i.e.*, more abstract) compared with easier words (*i.e.*, more concrete) increases sleep spindle power and density (Schmidt et al., 2006), and this change is associated with better memory performance. Together, this suggests that sleep spindles are related to initial encoding, and the efficient consolidation of the declarative memory trace for verbal information. This may occur through reactivation of the memory trace during sleep. For example, simultaneous EEG-fMRI studies, (Bergmann et al., 2011; Jegou et al., 2019) have found that the declarative memory trace for a paired associates task was strengthened during sleep, via reactivation of the brain structures recruited during learning (*i.e.*, hippocampus and

face/scene visual cortical areas), and this reactivation was tuned by variations in spindle amplitude.

1.4.1.2 Slow Wave Activity.

Declarative learning via word-pair learning increases slow-wave oscillation amplitude, as well as EEG coherence for slow-wave oscillatory (0.5-1.5 Hz), delta (1-4 Hz), slow-spindle (NREM2: 11.5-12.5 Hz; SWS: 9.5-10.5 Hz), and gamma bands (25-40 Hz) time-locked to the occurrence of the up-state of the slow-wave (Mölle et al., 2004; Mölle et al., 2009). Furthermore, increasing endogenous slow wave activity using transcranial direct current stimulation results in improvements in overnight retention of word-pairs (Marshall et al., 2004; Marshall et al., 2006b). One way that SWS may contribute to the consolidation of memory is through hippocampal reactivation. This is supported for spatial memories where neuroimaging has revealed hippocampal reactivation occurs during SWS, and the amount of reactivation is correlated with performance improvements the following day (Peigneux et al., 2004).

1.4.1.3 REM Sleep.

In contrast to the role of NREM sleep in the consolidation of declarative memory for simple verbal material (*i.e.*, word lists, word pairs) REM sleep deprivation has no effect on performance (Bertini & Torre, 1974; Castaldo et al., 1974; Chernik, 1972; Drosopoulos et al., 2007; Ekstrand, 1967; Ekstrand et al., 1971; Lewin & Glaubman, 1975; Smith, 1995; Tilley, 1981). However, some studies using prose passages or stories have found that the number of words recalled and the accuracy of recall are significantly impaired following REM sleep deprivation (Empson & Clarke, 1970; Tilley & Empson, 1978). This finding has been used to suggest that REM sleep may be important for declarative memory

consolidation. However, these studies used more complex stimuli to assess declarative memory compared to studies using paired-associates or rote memorization to assess declarative memory. The use of passages may not only assess simple memorization (as in declarative learning), but may also examine sentence structure and other aspects of language that REM sleep may be important for (for example, cognitive procedural skills).

1.4.2 The role of sleep in motor skill learning.

A detailed discussion of the role of sleep in motor skill learning is beyond the scope of the current thesis. Briefly, for procedural memory tasks that are cognitively simple, but involve the use of motor skills, offline gains in performance are observed only when there is an intervening period of sleep (Karni et al., 1995; Walker et al., 2002, 2003). Specifically, NREM sleep appears to be critical in the consolidation of motor skills (Conway & Smith, 1994; Sandys-Wunsch & Smith, 1991; Smith & MacNeill, 1994; Tweed et al., 1999), as there are post-learning increases in NREM2 sleep, and sleep spindle density (Barakat et al., 2011; Boutin et al., 2018; Fogel et al., 2007; Fogel & Smith, 2006). The role of sleep spindles in motor skill learning was investigated by Fogel and colleagues (2017) who found reactivation of brain regions recruited during motor skill learning (striato-cerebello-cortical network) time-locked to sleep spindles. The extent of reactivation was further correlated with post-sleep performance improvements. Altogether, this suggests that procedural tasks that are cognitively simple are consolidated during NREM sleep, with an important role for sleep spindles.

1.4.3 Sleep and cognitive procedural skills.

Given that more experienced second language learners use cognitive procedural skills for understanding grammar (*i.e.*, learning and applying implicit rules; Ullman, 2001a,

2001b, 2005), research on the role of sleep in consolidating cognitive skills may be important for understanding Late SLA. Sleep has been shown as vital to the consolidation of procedural memory that involve skills including problem solving and rule abstraction (Buchegger et al., 1991; Ellenbogen et al., 2007; Mandai et al., 1989; Mantua et al., 2016; Nielsen et al., 2015; Plihal & Born, 1997; Smith et al., 2004; Smith, 1993, 1996; Smith & Smith, 2003; Smith & Weeden, 1990; Smith & Wong, 1991; van Schalkwijk et al., 2019), an effect that is not observed after a period of wake (Doyon et al., 2009; Durrant et al., 2011; Fogel et al., 2007; Kuriyama et al., 2004; Nielsen et al., 2015; Plihal & Born, 1997; Smith & Smith, 2003; Wagner et al., 2004). Traditionally, cognitive procedural memory has been associated specifically with REM sleep (Peters et al., 2007; Smith et al., 2004; Smith & Smith, 2003; Smith & Weeden, 1990) and rapid eye movements themselves (Peters et al., 2007; Smith et al., 2004; Smith & Weeden, 1990), but there has also been some research showing that NREM sleep fine-tunes procedural memory consolidation for newly acquired cognitive strategies (Fogel et al., 2015; van Schalkwijk et al., 2019). This leads to the prediction that during the late phase of SLA, when the procedural memory system is implicated, REM sleep and rapid eye movements in particular may support the consolidation of language learning.

1.4.3.1 REM Sleep and cognitive procedural skills.

The idea that REM sleep is imperative to the consolidation of cognitively complex cognitive skills comes from three lines of evidence: (1) REM-sleep deprivation studies (Karni et al., 1994; Lewin & Glaubman, 1975; Plihal & Born, 1997, 1999a; Smith, 1993); (2) REM-inhibition studies (Sandys-Wunsch & Smith, 1991; Smith & Smith, 2003); and (3)

studies that observe learning-related changes in sleep states (Buchegger et al., 1991; Buchegger & Meier-Koll, 1988; Lewin & Gombosh, 1972).

Karni et al., (1994) demonstrated that a normal night of sleep improves performance on a visual texture discrimination task. Selectively depriving participants of REM sleep using forced arousal (by ringing a bell when they entered the sleep stage) resulted in no performance benefit of sleep; while selective NREM sleep deprivation did not impair sleep-related performance improvements. REM sleep deprivation using the half-night paradigm has been used to demonstrate that late sleep (REM dominant) benefits recall of mirror tracing skills (a cognitively complex procedural task; Plihal & Born, 1997), as well as wordstem priming performance (Plihal & Born, 1999a). Furthermore, total sleep deprivation as well as REM sleep deprivation impairs memory for an implicit complex logic task (Smith, 1993).

Alcohol has a REM-supressing effect that has been utilized to show that inhibiting REM impairs memory consolidation for cognitive skills (Smith & Smith, 2003), as well as for the acquisition of a logic task (Sandys-Wunsch & Smith, 1991). However, whether this effect is driven by a reduction in REM sleep duration or rapid eye movements is unclear as this methodology also reduces the number of rapid eye movements.

Lastly, REM sleep time appears to increase following tasks that involve complex implicit learning (Buchegger et al., 1991; Buchegger & Meier-Koll, 1988; Lewin & Gombosh, 1972). For example, Lewin and Gombosh (1972) demonstrated increases in time spent in REM sleep following learning tasks that involved divergent thinking. Furthermore, participants who learned complex trampolining skills (involving the acquisition of unfamiliar motor coordination) experienced a significant increase in REM-sleep (Buchegger

et al., 1991; Buchegger & Meier-Koll, 1988). In contrast, those who learned motor skills involved in soccer or dance (motor patterns that use normal locomotion) did not experience any changes in REM-sleep (Buchegger et al., 1991; Buchegger & Meier-Koll, 1988).

Generally, the number and density of rapid eye movements has been shown to increase following periods of intense learning (Smith & Lapp, 1991). For cognitively complex procedural memory tasks, there are post-learning increases in the number of rapid eye movements as well as rapid eye movement density (Peters et al., 2007; Smith et al., 2004). This increase in the number and density of rapid eye movements is correlated with the level of acquisition (Smith et al., 2004). Furthermore, targeted memory reactivation during REM sleep coinciding with rapid eye movements enhances the process of consolidation for rule learning (Smith & Weeden, 1990). For example, participants who acquired a set of complex rules while in the presence of a loudly ticking clock, and were then re-exposed to the ticking noise during subsequent sleep, time-locked to rapid eye movements, significantly improved in memory for the rules compared with controls (i.e., those who were not cued with the clock, and had reactivation coincident with rapid eye movements; those who were cued with the clock but were reactivated non-coincident with rapid eye movements; and those who were not cued and not reactivated; Smith & Weeden, 1990). Together, this suggests that rapid eye movements may be an important marker of learning performance for tasks that involve complex cognitive skills.

1.4.3.2 NREM2 and cognitive procedural skills

Using the mirror-tracing task (a cognitively complex procedural task), researchers observed that only those participants who experienced a change in sleep spindle size (amplitude x duration; known as spindle enhancers) from the control night to the learning

night showed long-term behavioural performance improvements (Schalkwijk et al., 2019). This suggests that spindle size is enhanced to support procedural learning, a finding that extends on previous research showing a relationship between spindle size and declarative memory consolidation (Schabus et al., 2004). As spindle size is implicated in both memory types, it may be that spindle size actually reflects general learning demands rather than an association with a specific memory domain.

For the Tower of Hanoi (a problem solving, cognitively complex procedural task), consistent with past research, an increase in REM sleep has been observed prior to the acquisition of a cognitive strategy, whereas sleep spindles and NREM2 are increased after the task has been mastered (Fogel et al., 2015). Based on these results, it has been suggested that NREM sleep may fine-tune the motor skills required to execute the solution to the problem that was previously enhanced by REM sleep (Fogel et al., 2015; Nielsen et al., 2015; Peters et al., 2007; Smith et al., 2004). Thus, NREM2 sleep may play a role in the refinement/automatization of cognitively complex skills, perhaps only after an initial period of REM-dependent consolidation of the new cognitive strategies. However, this relationship has not yet been fully elucidated.

1.4.4 Sleep & Language Acquisition.

Given the above studies that demonstrate the role of sleep in consolidating declarative and procedural memories, there is adequate rationale for suggesting a link between sleep and acquiring a new language. In support of this, studies have directly investigated what role sleep plays in specific aspects of language acquisition, including examining the role of sleep in: (1) assigning meaning to words (Fletcher et al., 2019; Tamminen et al., 2013; Tham et al., 2015); (2) enhancing phonological production (Durrant et al., 2011; Fenn et al., 2003;

Fostick et al., 2014; Gaskell et al., 2014); (3) integrating words into the mental lexicon (Davis et al., 2009; Dumay & Gaskell, 2007; Dumay & Gareth Gaskell, 2012; Henderson et al., 2012; Lindsay & Gaskell, 2013; Tamminen et al., 2010, 2013); and, (4) learning implicit grammar (Batterink et al., 2014; Gómez et al., 2006; Hupbach et al., 2009; Nieuwenhuis et al., 2013). Furthermore, sleep has also been examined in naturalistic language learning conditions (De Koninck et al., 1989a, 1990; Guerrien et al., 1989; Mandai et al., 1989).

1.4.4.1 Sleep & Semantics.

Sleep appears to be important for consolidating memory involved in assigning meaning to words (Fletcher et al., 2019; Tamminen et al., 2013; Tham et al., 2015). For example, in children, sleep has been shown to consolidate the meaning of novel words (Fletcher et al., 2019), and spindle duration predicted task improvement in response to these words (Fletcher et al., 2019). Learning words with fewer semantic neighbours (number of concepts that are semantically related) influences post-learning sleep by increasing slow wave activity, as well as the number of sleep spindles (Tamminen et al., 2013). Together, this suggests that sleep (in particular sleep spindles and slow wave activity) may stabilize semantic linguistic information and aid in the integration of semantic linguistic information into memory networks.

1.4.4.2 Sleep & Phonetics.

In phonology, there exist phonetic constraints on how syllables can be created, such that there are acceptable placements for phonemes as well as for how phonemes can be combined. In English, an example of a phonological speech production constraint would be that /bl/ can be used at the beginning of a syllable (*i.e.*, as in *blue*), but not at the end (i.e., *uebl*). Sleep consolidates learning phonological speech production constraints, and

specifically, implicit constraint learning is associated with SWS (Gaskell et al., 2014). Furthermore, the generalization of learned phonetic material to novel situations occurs only following a period of sleep compared to an equivalent period of wake (Gaskell et al., 2014).

Sleep appears to also have an important role for enhancing speech perception (Durrant et al., 2011; Fenn et al., 2003), and sleep deprivation appears to impair speech perception (Fostick et al., 2014). For example, one activity involved in speech perception is how to segment sequential speech into discrete words. This process refers to statistical learning (Saffran et al., 1996), and involves implicit abstraction and generalization processes. Sleep promotes abstraction of auditory probabilistic sequential structures, and the level of improvement in statistical learning is associated specifically with the amount of SWS obtained (Durrant et al., 2011). Interestingly, sleep also appears to have a role in recovering linguistic perceptual learning. Fenn et al. (2003) investigated speech perception using an artificial language task that involved both declarative memory (to form memories associated with newly learned words) and procedural memory (to establish a pattern over learned words that can be generalized to new instances). Sleep was shown to restore the memory trace for generalizing phonological categories across acoustic patterns, which had decayed across a period of wake (Fenn et al., 2003).

1.4.4.3 Sleep & the mental lexicon.

Sleep appears to benefit the integration of words into the mental lexicon (Davis et al., 2009; Dumay & Gaskell, 2007; Dumay & Gaskell, 2012; Tamminen et al., 2010, 2013). For example, one paradigm known as the lexical competition task is used for studying word-learning (Marslen-Wilson & Zwitserlood, 1989). Here, participants learn a new word, and then the extent of competition with previously consolidated words is examined. In adults

and children, a period of sleep promotes this integration of newly learned words into knowledge (Davis et al., 2009; Dumay & Gaskell, 2007; Dumay & Gaskell, 2012; Henderson et al., 2012), and is associated with increased spindle activity (Tamminen et al., 2010, 2013), as well as slow-wave activity (Tamminen et al., 2013). It has also been demonstrated that reactivating memories using cues during NREM sleep, improved vocabulary learning of foreign words, and slow-waves and theta oscillations are involved in this sleep-associated strengthening of memories (Schreiner & Rasch, 2015).

1.4.4.4 Sleep & Grammar learning

The role of sleep in learning grammar has been examined using artificial languages or grammar in infants (Gómez et al., 2006; Hupbach et al., 2009), as well as in adults (Batterink et al., 2014; Batterink & Paller, 2017; Nieuwenhuis et al., 2013). Studies in infants show that sleep promotes extraction of grammatical rules during language learning (Gómez et al., 2006; Hupbach et al., 2009).

In adults, sleep has been demonstrated to enhance learning of rule abstractions for artificial grammar (Nieuwenhuis et al., 2013). This effect appears specifically related to SWS and REM sleep (Batterink et al., 2014; Batterink & Paller, 2017). For example, targeted memory reactivation during SWS using phrases from a recently learned artificial language increases grammar generalization post-sleep (Batterink & Paller, 2017). In addition, Batterink et al., (2014) found that SWS and REM duration was related to learning a hidden article rule, with those participants who had greater SWS and REM sleep during a post-learning nap exhibiting increased sensitivity to the hidden linguistic rule (Batterink et al., 2014).

1.4.4.5 Sleep & Naturalistic Language Learning

Lastly, the role of sleep has been examined in naturalistic learning conditions including during the learning and translation of Morse code, and during intensive language learning of French. These studies find an important role of sleep in general, as well as a specific role of REM sleep for language learning (De Koninck et al., 1988, 1989a, 1990; Guerrien et al., 1989; Hébert & De Koninck, 1993, 1994; Mandai et al., 1989).

While Morse code is not considered a language, it still requires translation and has been suggested to use a combination of both declarative memory and cognitive skills (see Rasch & Born, 2013; Rauchs et al., 2005). Studies that focus on the role of sleep in Morse code learning have participants discriminate and translate Morse code signals. Learning Morse code results in an increase in the amount of REM sleep and the number of REM sleep periods (Mandai et al., 1989). Furthermore, the density of rapid eye movements is correlated with task performance (Mandai et al., 1989). Re-exposure to codes during phasic REM sleep, also increased performance compared with exposure during tonic REM sleep or no stimulation, implicating a role for rapid eye movements themselves in enhancing consolidation (Guerrien et al., 1989).

In a series of landmark studies by De Koninck and colleagues, changes in sleep architecture that support second language learning were examined (De Koninck et al., 1988, 1989a, 1990; Hébert & De Koninck, 1993, 1994). Here, Anglophone students taking a 6-week intensive French language learning course had PSG recordings completed throughout the course (pre, during, and post). They found a relationship between increases in REM sleep percentage and language learning efficiency (De Koninck et al., 1989a). This increase corresponded to an enhancement of REM sleep during the course that then subsided after the course was complete (De Koninck et al., 1989a). Furthermore, participants who made

significant progress in learning French also experienced an integration of the French language into their dreams earlier on, and experienced more French verbal communication during dreaming compared with those who made little progress (De Koninck et al., 1990).

Together, this suggests that REM sleep is integral in supporting SLA. However, the role of electrophysiological markers of memory, e.g., sleep spindles and rapid eye movements specifically, has yet to be examined. Given that language learning involves both a declarative memory component alongside a procedural component (Ullman, 2001, 2004, 2005), and sleep spindles are important markers of learning for declarative memory (see Fogel & Smith, 2011) while rapid eye movements are important markers of learning for cognitive procedural learning (see Smith, 2001), sleep spindles and rapid eye movements may both play important and distinct roles in consolidating learning for a second language. Thus, examining the roles of sleep spindles and rapid eye movements may shed light onto the neural processes that take place during SLA.

1.4.4.6 Sleep & Hemispheric lateralization during SLA

To date, only a handful of studies have examined interhemispheric lateralization during consolidation for SLA (Hébert et al., 1992; Hébert & De Koninck, 1993, 1994). Here, researchers examined lateralization effects during sleep in adults as they gained proficiency in the second language (at both early and late stages). These results reveal a hemispheric shift throughout the duration of the intensive second language course during REM sleep as participants become proficient in the language. The directionality of this shift has been reported as inconsistent across participants (Hébert et al., 1992), as well as from left-hemispheric dominance to hemispheric symmetry (Hébert & De Koninck, 1993, 1994). This leads to the idea that there may be moderators beyond age and proficiency (see Section

1.3.4) in determining if the second language memory trace is left-lateralized or not. Further research replicating these effects may lead to insights on this individual factor that seems important for determining where the second language representation is localized.

Chapter 2: Current Study

SLA is thought to be supported by procedural memory and declarative memory systems (for a review see, Hamrick et al., 2018). Specifically, in Ullman's declarative-procedural model of SLA (Ullman, 2001a, 2004, 2005), the early stages of adult second language learning is thought to rely on the declarative memory system for memorizing new word meanings and sounds, as well as for rudimentary grammar. In this way, word forms processed in the leaner's native language are memorized in the second language (Deng et al., 2016; Kimppa et al., 2019). For example, a beginner English second language learner may simply memorize that the past tense of *walk* is *walked*. With additional experience in the second language, a shift occurs to the procedural memory system for grammar (Ullman, 2001a, 2004, 2005). Specifically, as second language proficiency improves, heuristic rules, such as: regular verbs are conjugated in the past tense with the suffix *–ed*, would be employed to conjugate *walk* as *walked*. Direct evidence from artificial language acquisition studies support Ullman's declarative-procedural model of SLA (Ullman, 2001a, 2004, 2005) whereby individual differences in declarative memory predict early grammar skills, whereas differences in procedural abilities predict late grammar skills (Morgan-Short et al., 2014). Furthermore, procedural memory has been shown to moderate grammatical performance at the later stages of artificial language learning (Brill-Schuetz & Morgan-Short, 2014) as well as for experienced adult second language learning (Granena, 2013).

Wake is considered necessary for encoding and retrieval, whereas sleep is an opportune time for memory consolidation to unfold (i.e., the transformation of labile memory traces

into a more permanent form; for a review see, Peigneux et al., 2015). Distinct sleep states preferentially support consolidation for different memory types (see: Dual Process hypothesis; Gais & Born, 2004; Maquet, 2001; Rauchs et al., 2005; Smith, 2001a; and the Active System Consolidation hypothesis; Diekelmann & Born, 2010; Oudiette & Paller, 2013). For example, studies employing sleep deprivation (Castaldo et al., 1974), sleep vs. wake behavioural studies (Plihal & Born, 1997; Ruch et al., 2012), and targeted memory reactivation (Cairney et al., 2014) studies show that declarative memory depends on non-rapid eye movement (NREM) sleep, with sleep spindles (bursts of 11-16 Hz oscillatory activity in thalamocortical networks during NREM sleep) serving as an important marker of the consolidation process (for a review, see Fogel & Smith, 2011). On the other hand, REM sleep is advantageous for procedural skills, particularly those that require the acquisition of new rules and strategies (e.g., grammar). Evidence from studies involving REM-sleep deprivation (Plihal & Born, 1997, 1999b; Smith, 1993), REM-inhibition (Smith & Smith, 2003), targeted memory reactivation (Smith & Weeden, 1990), and sleep recording studies (Buchegger et al., 1991; Buchegger & Meier-Koll, 1988) have revealed that eye movements during REM are an important marker of the memory consolidation process (Smith, 2001a; Smith et al., 2004).

Given the involvement of declarative and procedural memory systems in SLA, and the contribution of sleep to memory consolidation, we propose that sleep may be involved in naturalistic SLA. In line with this, sleep has been shown to be important for certain aspects of language, including assigning meaning to words (Tamminen et al., 2013), phonological production (Gaskell et al., 2014), speech perception (Durrant et al., 2011), integrating words into the mental lexicon (Tamminen et al., 2010), and learning implicit grammar (Batterink et

al., 2014), as well as for SLA in a naturalistic setting (De Koninck et al., 1988, 1989b, 1990; Hébert et al., 1992; Hébert & De Koninck, 1993, 1994). We further suggest that distinct sleep states may be preferentially involved at different stages of SLA. For example, NREM sleep which is important for declarative memory consolidation, has been found to be important for processes required in the earliest stages of language acquisition including speech perception (Durrant et al., 2011). Furthermore sleep spindle activity is associated with assigning meaning to words (Tamminen et al., 2013), as well as integrating words into the mental lexicon (Tamminen et al., 2010). By contrast, REM sleep which is important for procedural memory consolidation, is important for processes required in the later stages of language acquisition such as grammatical skills (Batterink et al., 2014). In a series of naturalistic language acquisition studies (De Koninck et al., 1989b, 1990), the role of REM sleep was found to be involved in SLA. Over a the course of a six-week long intensive French second language learning program, it was observed that increased REM sleep was related to improvements in second language proficiency (De Koninck et al., 1989b). Furthermore, those who started dreaming in French earlier subsequently saw significant progress in French proficiency, compared with those who made little progress (De Koninck et al., 1990). Interestingly, a hemispheric shift was observed during REM sleep as participants gained proficiency in the second language (Hébert et al., 1992; Hébert & De Koninck, 1993, 1994), but the direction of this shift has been reported to differ across participants (Hébert et al., 1992) as well as shift from left-dominance to hemispheric symmetry (Hébert & De Koninck, 1993, 1994). Taken together, REM sleep appears to be involved in SLA, however, it remains to be investigated if rapid eye movements and sleep spindles are electrophysiological markers of SLA in a naturalistic setting.

The present follow-up study sought to examine how sleep supports SLA, and the unique electrophysiological correlates (e.g., rapid eye movements, spindles) at different stages of SLA (e.g., early vs. late). More specifically, we examined the relationship between neural oscillations and improvements in French proficiency over the course of an intensive French second language program. We also investigated whether interhemispheric lateralization of these electrophysiological signatures took place over the course of SLA. We hypothesized that **(1)** there will be learning-related changes in sleep spindle characteristics (density and size) and rapid eye movement (density) across the duration of an intensive second language learning course, as compared to a post-course follow-up. **(2)** During the early stage of SLA, it is predicted that changes in sleep spindle characteristics will correlate with improvements in French proficiency, whereas, **(3)** changes in rapid eye movements during the late stage of SLA will correlate with improvements in French proficiency. Lastly, **(4)** consistent with past research, we predicted that there may be greater left hemispheric participation during Early SLA for markers of sleep-related memory consolidation. While at Late SLA, this difference would disappear suggesting that generalization has taken place.

Chapter 3: Methods

3.1 Participants.

Thirteen participants were originally recruited for the study protocol from a six week-long intensive second language (French) learning course at the Second Language Institute in the University of Ottawa in 1991. However, the data from four participants were not converted to a digital format, and one participant was excluded for failing to comply with experimental protocols resulting in a final sample of eight participants (5 females, 18-28 years, M = 24). Participants were unilingual Anglophones that were enrolled in a post-secondary institution in Ontario. A letter was mailed to potential candidates describing the general nature of the research (see **Appendix A**). Interested participants contacted the Sleep Research Laboratory at the University of Ottawa for more information and completed a brief telephone screening interview (see **Appendix B**). All participants had little to no prior French language knowledge, as assessed during the telephone screening interview. During the telephone interview, participants were screened for sleep disorders (e.g., insomnia), psychological disorders (e.g., severe anxiety, depression, phobias), medical conditions (e.g., asthma, epilepsy), and neurological disorders (e.g., brain damage, tumors). All potential participants underwent an initial acclimatization and sleep disorders screening night (see **Figure 1** for the experimental protocol), consisting of electroencephalographic (EEG) activity recorded from F3, F4, W1 and W2 scalp locations, electrooculogram (EOG), electromyogram (EMG), and additional measures for nasal airflow and anterior lower leg muscles. This was used to identify signs of sleep disorders including apnea, movement disorders, and other parasomnias.

Participants were also asked to complete a series of screening questionnaires including the Minnesota Multiphasic Personality Inventory (Hathaway & Mckinley, 1940; to screen for signs of psychological or psychiatric conditions; see **Appendix C**), the Edinburgh Handedness Inventory (Oldfield, 1971; to identify handedness; see **Appendix D**), the State-Trait Anxiety Inventory (Spielberger et al., 1983; to screen for situational and generalized anxiety; see **Appendix E**), the Sixteen Personality Factor Questionnaire (Cattell et al., 1982, 1949; to screen for signs of psychological or psychiatric conditions; see **Appendix F**), and the Beck Depression Inventory (Beck et al., 1961; to screen for depression; see **Appendix G**). All participants were encouraged to abstain from daytime napping, as well as from consuming non-prescription drugs, caffeine, nicotine, and alcohol throughout the duration of the study. Throughout participation in the study, participants were also asked to log information about their daily activities including notable events of their day, bedtime, wake time, medications taken, alcohol consumption, and dream content.

All participants were given a letter of information, provided written informed consent prior to participation (see **Appendix H)**, and were financially compensated for their participation. Furthermore, students completing the immersion program were granted 6 course credits at the University of Ottawa (with equivalencies for other Canadian post-secondary institutions). This study was approved by the University of Ottawa Research Ethics Board.

Participants in the intensive, naturalistic second language learning program were required to sleep in residence on campus for the duration of their participation in the language learning program. The program included both immersion and explicit modes of learning (see **Appendix I)**. For example, immersion was encouraged through individually

pairing students to share a room with a student whose first language was French. Social activities were also organized throughout the program (*i.e.,* social gatherings, sports activities, picnics, parties, etc.) so that students had the opportunity to become immersed in their new language and practice French in social settings. In addition, an informal seminar series conducted throughout the course focused on language learning within the French Canadian cultural context. Formal French instruction was conducted through a program that ran from Monday to Friday (with occasional weekends) and included six hours of French language curriculum per day. Here, students were grouped according to their level of capability in French and evaluated via a self-assessment.

3.2 French Proficiency Scores.

The French proficiency of the participants was assessed via the Ministère French Test, which is a measure of oral and reading/writing comprehension administered by the <*Gouvernement du Québec*> and the <*Ministére de l'Éducation*> (see **Appendix J**). The assessments included: 25 questions used to measure student's ability to understand spoken French; 12 questions that measured student's ability to read and comprehend French; and 8 questions that were used to measure student's ability to write French. The assessments were completed before the intensive language learning program (during the adaptation and screening nights), as well as after completion of the program (during the follow-up nights). Scoring of the assessments was completed by the <*Ministère de l'Éducation*>.

3.3 Polysomnographic Recording and Analysis.

A Nihon Kohden Polygraph (Model 4314- B) EEG system was used to perform in-laboratory PSG recordings. Electrical activity recorded from EEG, EOG, and EMG channels were amplified by the polygraph, digitized by an adapter recording equipment (Vetter

Digital, model 400090). Polysomnograph signals were digitized using an analog to digital signal converter (located in a microcomputer PC 486) at a sampling rate of 256 Hz, and filtered at 64 Hz with a low-pass filter. Data was then downsampled to 128 Hz and converted to European Data Format (EDF). EEG was measured at four electrode sites: parietal-temporal over Wernicke's area (W1 and W2); and frontal (F3 and F4). EEG and EOG (placed on the outer canthus of the left and right eyes according to established standards and procedures: (Jasper, 1958; Rechtschaffen & Kales, 1968) were referenced to the averaged mastoid derivations (M1 and M2) and placed according to the international 10-20 electrode placement system (Jasper, 1958). A submental EMG channel was recorded as a bipolar derivation. Manual sleep stage scoring, according to standard criteria (Iber et al., 2007), was completed using the EEGLAB (Delorme & Makeig, 2004) compatible, SleepSMG toolbox (http://sleepsmg.sourceforge.net/index.html). The sleep variables of interest obtained from the PSG recording nights included the total sleep time (TST); sleep efficiency (SE); sleep onset latency (SOL); wake after sleep onset (WASO); minutes and percentage of time spent in NREM1, NREM2, SWS, and REM sleep. TST was calculated as the total time spent asleep between "lights off" and "lights on". SOL was calculated as the time from "lights off" to the first epoch of sleep. SE was calculated as a percentage of the total time spent in bed actually sleeping between "lights off" and "lights on" divided by the total time in bed. WASO was defined as epochs following sleep onset that were scored as wake. Sleep stage minutes were calculated as the time between "light off" and "lights on" scored as NREM1, NREM2, SWS, and REM. Lastly, sleep stage percentages were calculated as the percentage of time between "light off" and "lights on" scored as NREM1, NREM2, SWS, and REM divided by TST.

3.4 EEG Analyses.

3.4.1 EEG Preprocessing.

EEG data was digitally filtered in MATLAB (Mathworks, Natick, Massachusetts , USA) using a zero-phase, finite impulse response filter implemented in the MATLAB toolbox EEGLAB (Delorme & Makeig, 2004; function 'pop_eegfiltnew.m') on EEG channels (passband edges at 0.3-35 Hz, transition bandwidth of 0.3), EOG channels (passband edges at 0.3-10 Hz, transition bandwidth of 0.3), and the EMG channel (passband edges at 10-50 hz, transition bandwidth of 2.5).

3.4.2 Sleep Spindle Detection.

Sleep spindle data was extracted from artifact-free, NREM sleep epochs. Automatic spindle detection was done using a previously validated method (Ray et al., 2015) implemented in EEGLAB-compatible software (Delorme & Makeig, 2004). Briefly, this detection method extracts spindle-related phasic changes in sigma relative to background sigma activity through a complex demodulation transformation of the EEG signal. The signal is z-score transformed using a 60 second window over the length of the recording. Spindles are then detected using a threshold method (z-score above 99^{th} percentile). Parameters for the spindle detector included a bandwidth of 5 Hz centered around a carrier frequency of 13.5 Hz (11-16 Hz; Iber et al., 2007). Only the EEG electrodes over Wernicke's area (W1 and W2) were used for subsequent analysis based on the importance of this area to language learning (Bloch et al., 2009; Hillis et al., 2001; Wernicke, 1970). The spindle variables of interest extracted from the automated detection method included spindle size (duration x amplitude), and density (number of spindles per minute of NREM2 and SWS) at electrode sites W1 and W2.

3.4.3 Rapid Eye Movement Detection.

Eye movements during REM sleep were automatically detected on left and right EOG channels using an adapted version of Yetton et al.'s (2016) implementation of the Hatzilabrou et al. (1994) matched filtering algorithm. Briefly, the matched filtering algorithm consists of bandpass filtering the data at 0.5 – 10 Hz, windowizing, and then removing the DC offset. Each hamming smoothed window was compared to a hamming smoothed template of a typical eye movement. False positives were removed with a monocular amplitude threshold at each channel (23 μV). The eye movement variable of interest extracted from the rapid eye movement detection included rapid eye movement density, which was calculated as the number of rapid eye movements per minute of REM sleep.

3.4.4 Event-Related Spectral Perturbation (ERSP).

In order to identify activity in the EEG time-locked to eye movements during REM sleep, an ERSP analysis on EEG power spectral changes were investigated using eye movement peaks as the events of interest. Specifically, using EEGLAB (Delorme & Makeig, 2004), data for each participant was epoched into 4 second windows (-2000 to 2000 ms), time locked to the peak of eye movements during REM sleep. The average number of events used for each condition was: 940 (*SD* = 525) for the Early phase, 848 (*SD* = 411) for the Late phase, and 944 (*SD* = 598) for the Follow-up. The EEGLAB function ‘newtimef.m’ (Delorme & Makeig, 2004) was used for time-frequency analysis. This function uses Morlet wavelets to decompose signals into their corresponding time-frequency representations. The number of wavelets used was from 3 cycles at 4 Hz to 7.5 cycles at 20 Hz in 132 linearly-spaced frequencies corresponding to each frequency bin, and 300 time points (from -1583.6

to 1583.6 ms) with a window size of 213 samples wide (832.03 ms). Power estimates (in decibels) were baseline corrected using a divisive baseline from -2000 ms to 0 ms.

3.5 Procedure.

Using an entirely within-subjects design, participants completed a total of nine sleep recordings at the University of Ottawa Sleep Research Laboratory, before, during and following the intensive second language learning course (see **Figure 1** for the experimental protocol). For the adaptation and screening nights, three sleep recordings took place two weeks prior to the course beginning, which served to screen participants for sleep disorders as well as acclimatize the participants to sleeping in the research laboratory. During the adaptation and screening nights, the participants completed a series of screening questionnaires, as well as the pre-course Ministère French Test to assess their French language proficiency prior to beginning the course. For the early acquisition (Early) nights, two sleep recordings took place during the second or third week of the course, and, similarly, for the late acquisition (Late) nights, two sleep recordings occurred at the fifth or sixth week of the course. Finally, for the follow-up (Follow-up) nights, two sleep recordings took place two weeks after the course concluded. During the follow-up nights, the participants completed the post-course Ministère French Test to assess their French language proficiency following completion of the course.

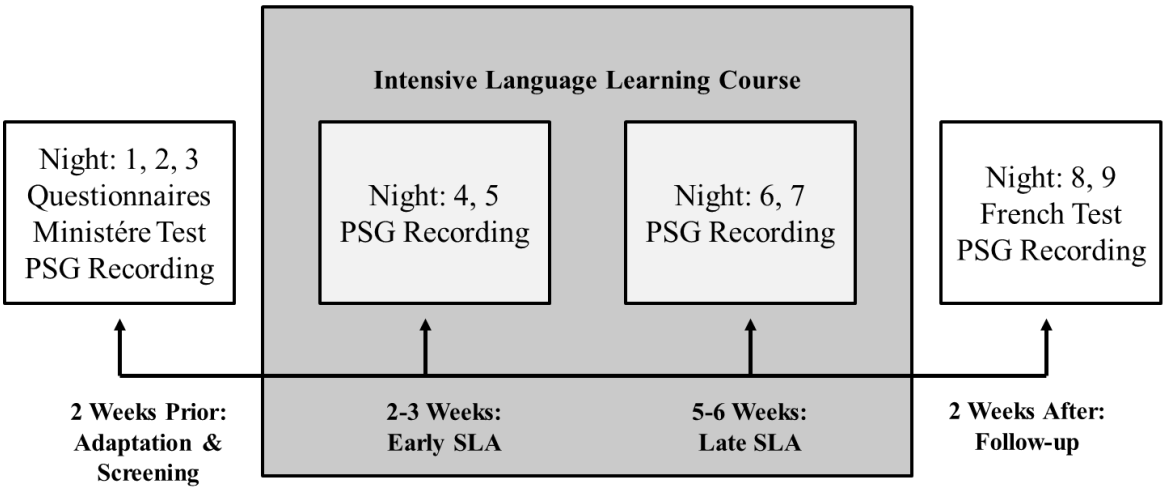


Figure 1. The experimental protocol. Participants first completed the "Adaptation & Screening" nights two weeks prior to beginning the course. During these nights, participants completed a battery of screening questionnaires, the Ministère French Proficiency Test and three PSG recordings. Two to three weeks into the course, participants came back into the lab and completed the early acquisition (Early) nights. During these nights, participants completed two PSG recordings. Similarly, five to six weeks into the course, participants came back into the lab and completed the two late acquisition (Late) PSG nights. Finally, two weeks after the course had ended, participants came back into the lab for the two follow-up (Follow-up) PSGs.

3.6 Statistical Analysis.

3.6.1 French Proficiency Scores.

A paired samples t-test was used to compare pre- (before the adaptation and screening nights) and post- (after the follow-up nights) scores on the Ministère French Test in order to confirm improvements in French proficiency following completion of the intensive second language learning course. To quantify individual improvements in French proficiency, difference scores were computed for each participant (post- minus pre- scores).

3.6.2 Sleep Architecture.

TST, SE, SOL, WASO, NREM1 (minutes & %), NREM2 (minutes & %), SWS (minutes & %), and REM (minutes & %) were each entered into repeated measures

ANOVAs to investigate changes in sleep architecture during (Early, Late) and after the completion (Follow-up) of the intensive second language learning course.

3.6.3 Sleep Spindles.

Repeated measures ANOVAs were used to investigate changes in sleep spindles (density & size) during (Early, Late) and following (Follow-up) the intensive second language learning course. In addition, the change in sleep spindle density and size across nights (Early phase to Late phase, Early phase to Follow-up, Late phase to Follow-up), for each electrode (W1 and W2), during NREM2 and SWS was correlated with the French proficiency difference scores in order to examine the relationship between night-to-night changes in sleep spindles and improvements in SLA.

3.6.4 Rapid Eye Movements.

Repeated measures ANOVAs were used to investigate changes in rapid eye movement density during (Early, Late) and following (Follow-up) the intensive second language learning course. In addition, a correlational analysis looking at change in eye movement density during REM sleep across nights (Early phase to Late phase, Early phase to Follow-up, and Late phase to Follow-up) and the calculated French proficiency difference scores were used to investigate the relationships between night-to-night changes in rapid eye movements and improvements in SLA.

3.6.5 Event-Related Spectral Perturbation (ERSP).

Statistical analysis on ERSP data was conducted using Fieldtrip (Oostenveld et al., 2011) implemented in EEGLAB (Delorme & Makeig, 2004). ERSP data was examined for frequencies from 4 Hz to 20 Hz (132 frequency points); within the time range from -500 ms to 500 ms (95 time points). An analysis of the changes in power across nights (Early phase

to Late phase, Early phase to Follow-up, and Late phase to Follow-up) was conducted. To control the Type 1 family-wise error rate, a cluster-based analysis approach on pairs of time-frequency information was used (alpha = 0.05). A cluster based analysis assumes that data points are not independent from one another and the values in neighbouring time or frequency points are likely to be related (methodology described in Maris & Oostenveld, 2007). A weighted cluster mean criterion was used, which considers both the cluster size and magnitude of the cluster test statistic (Hayasaka & Nichols, 2004). A Monte Carlo permutation statistical test was done with 10,000 randomizations (methodology described in Maris, 2012).

A subsequent follow-up correlational analysis was used to investigate the relationship between improvements in second language proficiency and significant changes in ERSP.

3.6.6 Interhemispheric lateralization during SLA.

To examine lateralization of SLA, differences between the left (W1) and right (W2) were analyzed for sleep spindles (size and density) and ERSP data time-locked to rapid eye movements. For spindle size and spindle density, paired sample t-tests were used to examine hemispheric differences across the stages of learning (Early, Late, and Follow-up) for both NREM2 and SWS. A cluster-based analysis conducted in Fieldtrip on ERSP data (Oostenveld et al., 2011; see 2.5.5 for methodology) was used to examine differences in EEG activity time-locked to rapid eye movements between the left (W1) and right (W2) hemisphere at each stage of learning (Early, Late, and Follow-up).

Chapter 4: Results

4.1 Language Proficiency Results.

4.1.1 Ministére French Test.

To investigate improvements in French proficiency following completion of the intensive second language learning course, a paired samples t-test was used to compare pre- to post-course French proficiency scores. The results revealed a significant increase in scores from pre- to post- course ($t_{1,7} = 4.75$, $p = 0.002$; see

Table 1), suggesting that the students completing the intensive second language learning program did indeed improve in French proficiency as a result of their participation in the program.

Table 1. Mean (SEM) and range of French proficiency test scores on the Ministére French Exam at the pre- and post-course time periods.

Testing Time Period	**Test Scores**	
	Mean ± SEM	*Range*
Pre-course	32.53 (11.17)	0 – 83.8
Post-course	56.53 (6.65)	32.4-82.4

4.2 Electrophysiological Results.

4.2.1 Sleep Architecture

Repeated measures ANOVAs were used to investigate changes in sleep architecture between the Early, Late and Follow-up nights. There was no significant effect of night for any sleep architecture variables (see **Table 2**), suggesting that gross sleep architecture was not altered over the course of, or following SLA.

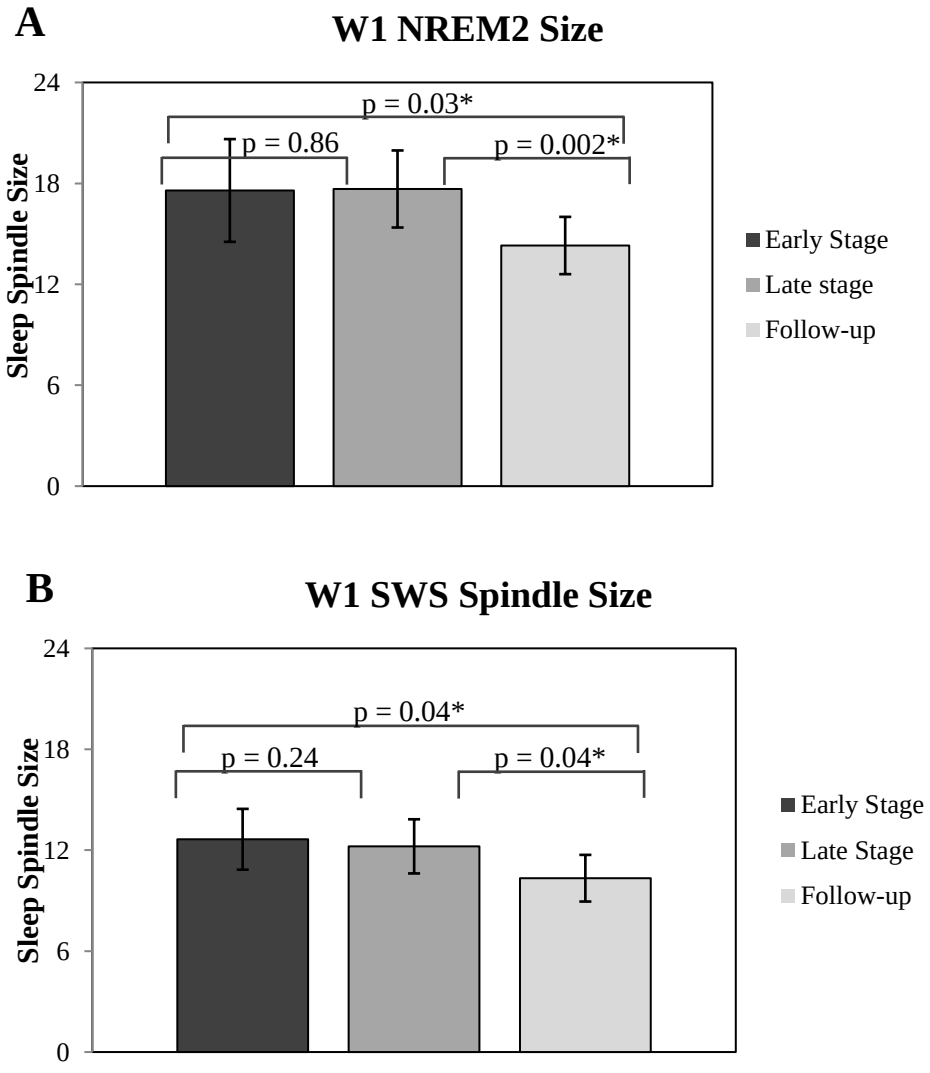
Table 2. Mean (SEM) and ANOVA results for sleep architecture on Early, Late and Follow-up nights.

Sleep Variable	Night			ANOVA Results	
	Early	*Late*	*Follow-up*	*F*	*P*
Total sleep time (h)	7.26 (0.14)	7.32 (0.11)	7.44 (0.12)	1.24	0.3
Sleep onset latency (min)	5.75 (1.6)	8.94 (3.15)	9.13 (2.29)	0.86	0.45
Sleep efficiency (%)	97.29 (0.64)	97.88 (0.59)	97.22 (1.47)	0.31	0.74
Wake after sleep onset (min)	12.31 (2.95)	9.63 (2.78)	12.25 (6.82)	0.26	0.78
% NREM1	1.36 (0.29)	1.32 (0.42)	1.28 (0.51)	0.02	0.98
% NREM2	48.75 (2.87)	49.46 (2.14)	50.33 (3.38)	0.26	0.77
% NREM3	24.82 (3.13)	22.72 (2.28)	23.4 (3.58)	1.01	0.39
% REM	25.07 (0.930	26.51 (2.05)	24.99 (1.83)	0.34	0.72

4.2.2 Sleep Spindles.

Repeated measures ANOVAs were used to investigate changes in sleep spindles between the Early, Late and Follow-up nights. There was no effect of night for spindle

density at either W1 or W2 electrodes during NREM2 or SWS (see **Table 3).** However, there was a significant effect of stage of SLA for spindle size during NREM2 ($F_{2,14}$ = 5.6, p = 0.016, η2 = 0.44) and SWS ($F_{2,14}$ = 3.92, p = 0.044, η2 = 0.36) at W1, and for SWS ($F_{2,14}$ = 4.39, p = 0.03, η2 = 0.354) but not NREM2 ($F_{2,14}$ = 1.98, p = 0.17) at W2 (see **Table 3**). Follow up t-tests (see **Figure 2**) revealed that this effect was driven by the differences between Early and Follow-up at W1 during NREM2 (t = 2.61, p = 0.03) and SWS (t = 2.48, p = 0.038) and at W2 during SWS (t = 2.55, p = 0.034), as well as between Late and Follow-up at W1 during NREM2 (t = 4.35, p =0.002) and SWS (t = 2.43, p = 0.041) and at W2 during SWS (t = 2.97, p = 0.018)



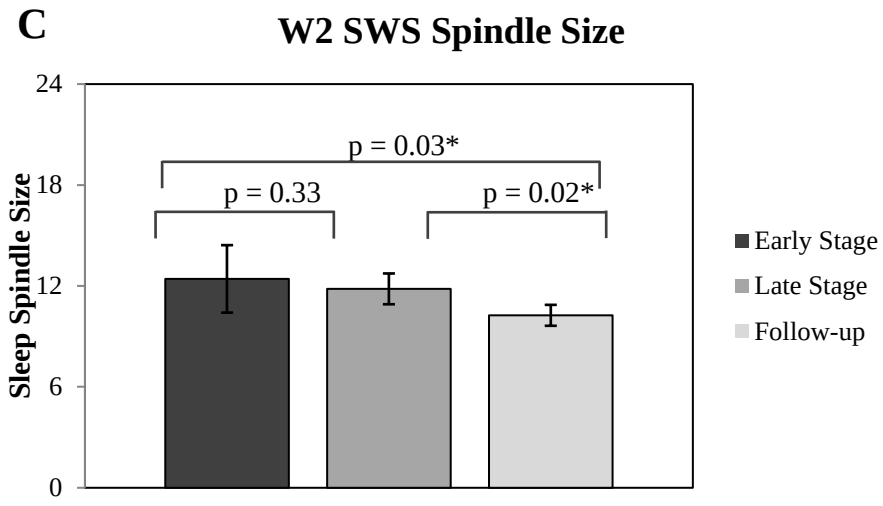


Figure 2. Results of the follow up t-tests for spindle size at (A) electrode W1 during NREM2, (B) electrode W1 during SWS, and (C) electrode W2 during SWS. Error bars denote calculated confidence intervals.

Table 3. Mean (SEM) and ANOVA results for the sleep spindle variables (size and density), and REM density across the nights (Early, Late and Follow-up).

Stage	**Site**	**Variable**	**Night**			**ANOVA**		
			Early	*Late*	*Follow-up*	*F*	*p*	h_p^2
NREM2	*W1*	Spindle Size	16.43 (1.62)	16.92 (1.3)	13.64 (0.87)	5.6	0.02*	0.44
		Spindle Density	1.61 (0.21)	1.81 (0.29)	1.66 (0.2)	0.16	0.86	0.02
	W2	Spindle Size	15.9 (1.76)	15.78 (0.63)	13.89 (0.68)	1.98	0.17	0.2
		Spindle Density	1.64 (0.26)	1.86 (0.25)	1.71 (0.2)	0.08	0.93	0.01
SWS	*W1*	Spindle Size	12.65 (0.99)	12.23 (0.88)	10.33 (0.76)	3.92	0.04*	0.36
		Spindle Density	4.3 (0.2)	4.19 (0.18)	4.05 (0.16)	1.51	0.26	.018
	W2	Spindle Size	12.42 (1.09)	11.83 (0.5)	10.25 (0.34)	4.39	0.03*	0.35
		Spindle Density	4.03 (0.18)	4.18 (0.2)	4.09 (0.16)	0.04	0.97	0.00
REM		REM Density	8.5 (2)	8.04 (1.63)	7.89 (2.02)	.034	.967	.005

Pearson's correlational analyses were used to investigate the relationship between improvements in French proficiency and sleep spindle variables (density and size) at the different stages of language acquisition (see **Table 4**). There was a significant positive correlation between improvement in French proficiency and change in spindle density from Early to Late during NREM2 ($r = .827$, $p = .011$) and SWS ($r = .77$, $p = .025$) at W1 (see **Figure 3**), but not W2. Spindle size was not associated with SLA (see **Table 4**). Suggesting that, despite no group difference in spindle density over the course of SLA, individuals with a greater increase in spindle production during the Early stage of SLA improved the most in French proficiency. There was no association between the improvement in second language proficiency and changes in spindle density or size from Early to Follow-up, or Late to Follow-up (see **Table 4**).

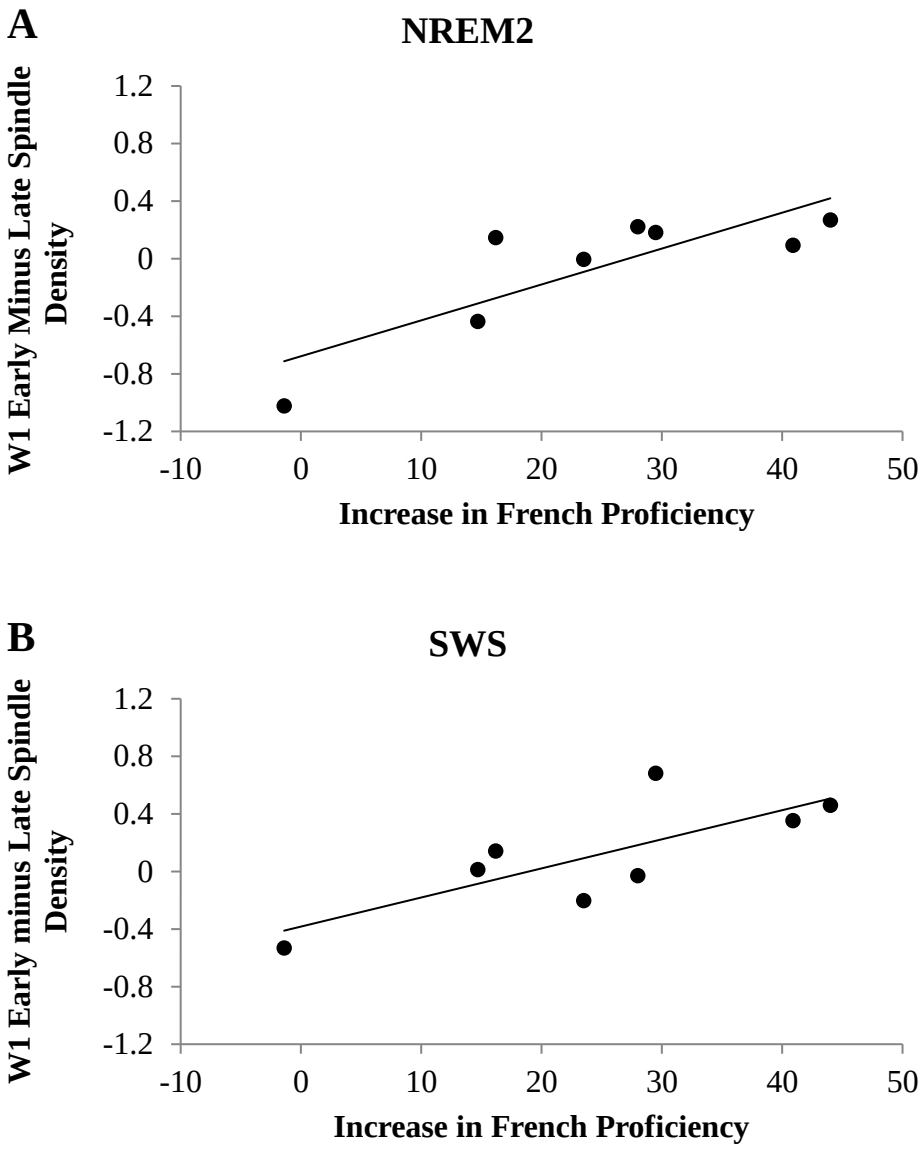


Figure 3. Scatterplots showing the relationship between the increase in French proficiency and Early minus Late spindle density at electrode W1 for both (A) NREM2 ($r = 0.83$, $p = 0.01$) and (B) SWS ($r = 0.77$, $p = 0.03$).

Table 4. Results of the correlational analysis examining the relationship between improvements in French proficiency and sleep spindle variables (size and density) and REM density.

Stage	Site	Variable	Early – Late		Early– Follow-up		Late – Follow-up	
			r	***p***	***R***	***p***	***r***	***p***
NREM2	*W1*	Spindle Size	0.35	0.4	-0.06	0.89	-0.47	0.24
		Spindle Density	0.83	0.01*	0.17	0.69	-0.68	0.07
	W2	Spindle Size	-0.33	0.42	-0.4	0.33	-0.3	0.47
		Spindle Density	0.15	0.73	-0.37	0.36	-0.5	0.2
SWS	*W1*	Spindle Size	0.38	0.36	-0.09	0.83	-0.34	0.42
		Spindle Density	0.77	0.03*	0.3	0.47	-0.44	0.28
	W2	Spindle Size	-0.29	0.49	-0.31	0.45	-0.1	0.8
		Spindle Density	0.01	0.98	-0.24	0.57	-0.24	0.57
REM		REM Density	-0.47	0.25	0.07	0.88	0.46	0.25

4.2.3 Rapid Eye Movements.

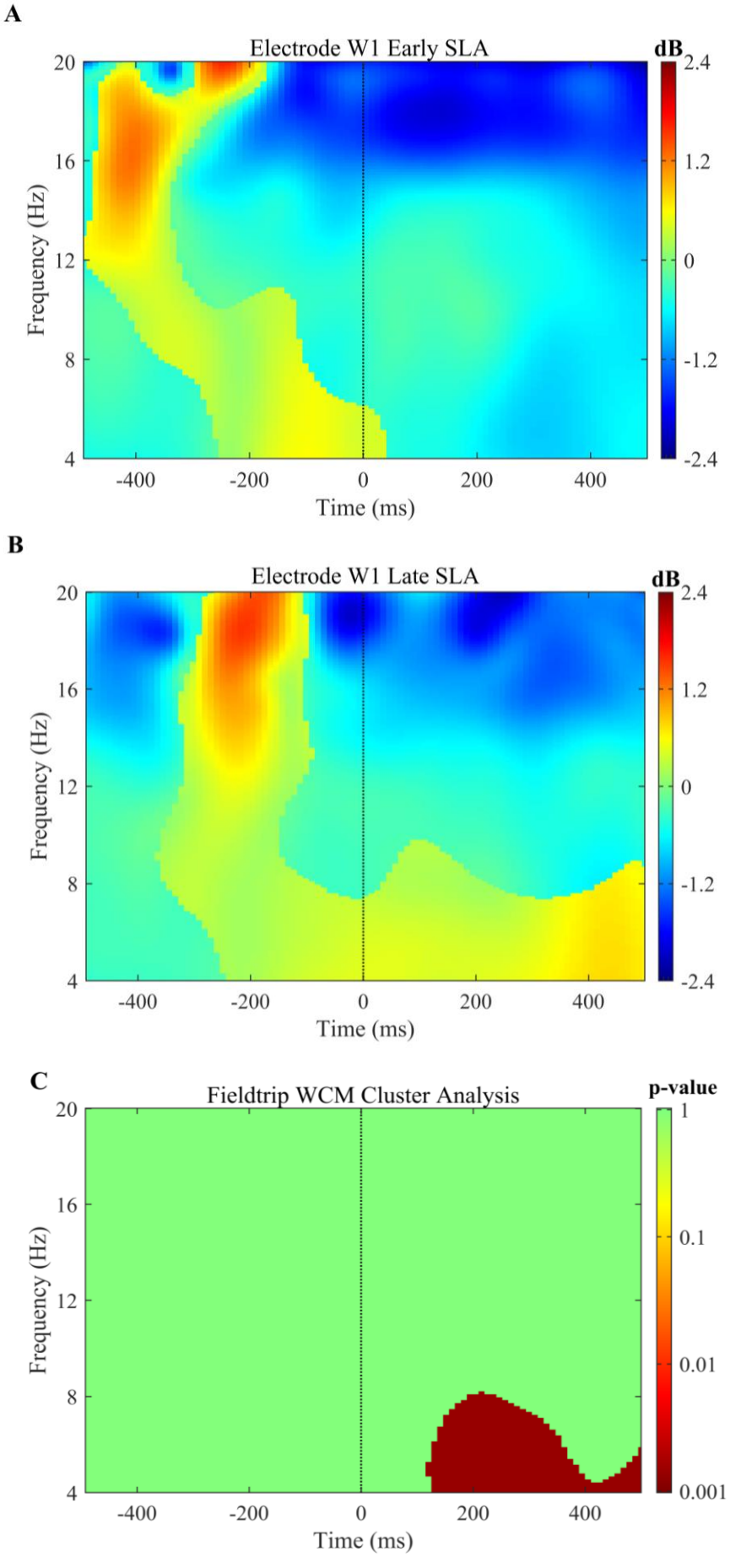
Repeated measures ANOVAs were used to investigate changes in rapid eye movements between the Early, Late and Follow-up nights. There was no significant effect of night for REM density ($F_{2,14}$ = 0.034, p = .967; **Table 3**), suggesting that REM density did not differ between stages of second language learning.

Pearson's correlational analyses were used to investigate the relationship between improvements in French proficiency and REM density. There was no significant correlation

(see **Table 4**) between improvements in French proficiency and change in REM density for Early to Late ($r = -0.47$, $p = 0.25$), Early to Follow-up ($r = 0.07$, $p = 0.88$), or Late to Follow-up ($r = 0.46$, $p = 0.25$).

4.2.3 Event-Related Spectral Perturbation (ERSP).

Results of the ERSP were subjected to a nonparametric cluster-based permutation analysis in order to analyze the changes in event-related EEG power time locked to rapid eye movements across nights (*e.g.*, Early vs. Late; Early vs. Follow-up; and Late vs. Follow-up). ERSP indicated that there was a significant effect of stage of second language learning at W1 comparing Early and Late ($p = 0.002$; see **Figure 4**). This corresponded to a cluster approximately 100-500 ms after the peak of the eye movement during REM sleep demonstrating increased theta power in the late stage of SLA. No effects were found using the cluster-based permutation analysis to examine changes in event-related EEG power time-locked to rapid eye movements for Early-vs.-Follow-up or Late-vs.-Follow-up ($p > 0.05$, see **Appendix K**).


A
Electrode W1 Early SLA
dB
2.4
1.2
0
-1.2
-2.4
Frequency (Hz)
20
16
12
8
4
-400
-200
0
200
400
Time (ms)
B
Electrode W1 Late SLA
dB
2.4
1.2
0
-1.2
-2.4
Frequency (Hz)
20
16
12
8
4
-400
-200
0
200
400
Time (ms)
C
Fieldtrip WCM Cluster Analysis
p-value
1
0.1
0.01
0.001
Frequency (Hz)
20
16
12
8
4
-400
-200
0
200
400
Time (ms)

In a follow-up analysis, we tested whether the increase in theta power at 100-500 ms during late SLA time-locked to rapid eye movements was correlated with improvements in French proficiency. Here, averaged power values were extracted for each participant in the theta band (4-8 Hz) from 100 to 500 ms post-peak of the eye movement. This revealed a significant positive correlation between the change in theta power (from Early to Late) and French proficiency ($r = 0.8$, $p = 0.02$, $r^2 = 0.64$; see **Figure 5**). In other words, students who had more theta power during the late stage of SLA improved more in French over the course of intensive language learning.

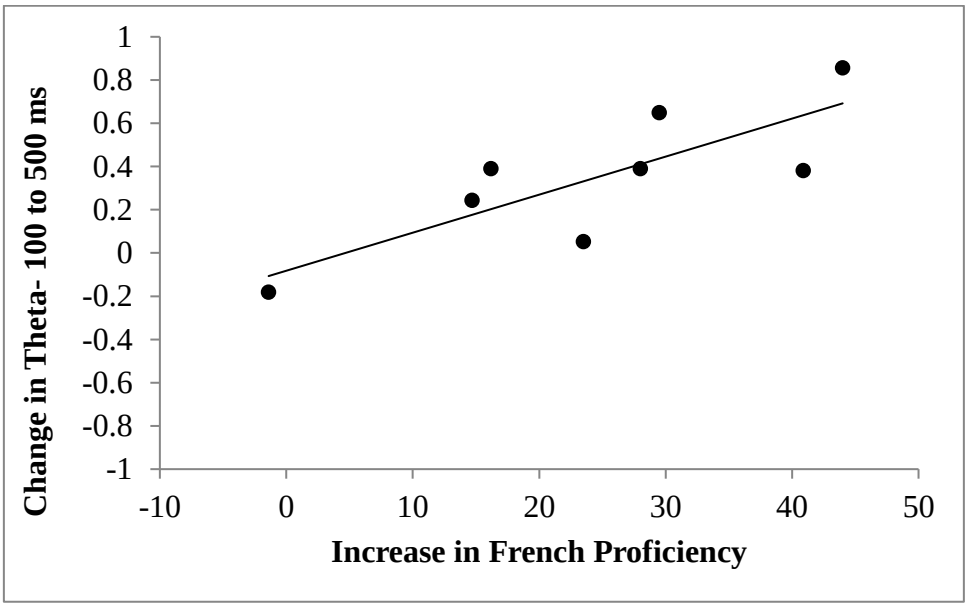


Figure 5. Scatterplot of the relationship between the change in theta power from early to late stage of SLA (Late minus Early) at 100 to 500 ms time-locked to eye movements during REM sleep.

4.2.5 Interhemispheric lateralization across SLA.

Paired samples t-tests (W1 – W2) were used to examine lateralization effects over Wernicke's area between the left and right hemisphere for spindle size as well as spindle density. Results indicated there were no significant lateralization effects for sleep spindle

density during NREM2 at Early SLA ($t_7 = 1.01$, $p = 0.35$), Late SLA ($t_7 = 0.39$, $p = 0.7$), and Follow-up ($t_7 = 0.22$, $p = 0.83$), as well as for SWS at Early SLA ($t_7 = 1.65$, $p = 0.14$), Late SLA ($t_7 = 0.12$, $p = 0.91$), or Follow-up ($t_7 = -0.44$, $p = 0.67$). Furthermore, there were no lateralization effects for sleep spindle size during NREM2 at Early SLA ($t_7 = 0.5$, $p = 0.64$), Late SLA ($t_7 = 1.07$, $p = 0.32$), or Follow-up ($t_7 = -0.12$, $p = 0.9$), as well as for SWS at Early SLA ($t_7 = 0.38$, $p = 0.71$), Late SLA ($t_7 = 0.54$, $p = 0.6$), or Follow-up ($t_7 = 0.18$, $p = 0.86$).

Lastly, results of the ERSP were used to compare the difference between left and right hemisphere electrodes at Early SLA, Late SLA, and Follow-up. A cluster based-permutation analysis implemented in Fiedltrip (Oostenveld et al., 2011) was used for statistical analyses. The results of the cluster analysis indicated no significant difference between data at the W1 (left hemisphere) and W2 (right hemisphere) electrodes for Early SLA ($p > 0.05$), Late SLA ($p > 0.05$), or Follow-up ($p > 0.05$; see **Appendix K**).

Chapter 5: Discussion

The current follow-up study aimed to investigate how sleep-related markers of memory consolidation could be informative about the neural basis of the acquisition of a second language, and the putative role that sleep plays in SLA. The current investigation revealed that: **(1)** spindle size, but not REM density was elevated throughout the course (at both Early and Late SLA) compared to following the course (Follow-up) once intensive SLA was completed, **(2)** improvements in French proficiency were associated with the change in spindle density between Early SLA and Late SLA, whereby participants who had more spindles during Early SLA improved more in French proficiency, **(3)** on the other hand, while there was no change in REM density during SLA and no correlation between French proficiency and REM density, theta activity time-locked to rapid eye movements in REM sleep at approximately 100-500 ms was increased during Late SLA compared to Early SLA, and this change in theta activity from Early to Late was positively correlated with French improvement scores, and, **(4)** there was no hemispheric effects for lateralization of sleep spindles or rapid eye movements. Together, these results extend previous knowledge about naturalistic SLA and align with Ullman's Declarative-Procedural model of SLA (Ullman, 2001a, 2004, 2005) to include a role of sleep. In sum, the present findings suggest that sleep spindles support learning, particularly during Early SLA, while theta activity time-locked to rapid eye movements supports learning during Late SLA.

5.1 Sleep-related markers of language learning.

5.1.1. Changes in sleep over the course of SLA.

We observed elevated spindle size throughout SLA. This finding is consistent with research demonstrating that spindles may support both declarative and procedural memory consolidation, rather than a distinct memory system. For example, changes in spindle characteristics have been identified in response to both declarative (Schabus et al., 2004, 2008), cognitively complex procedural (Fogel et al., 2015; van Schalkwijk et al., 2019) learning as well as procedural skills and sequence learning (Fogel et al., 2007; Fogel & Smith, 2006; Morin et al., 2008; Nishida & Walker, 2007; Walker et al., 2002). Thus, taken together, the present findings support the idea that spindles are related to the overnight reprocessing of both declarative and procedural memory over the course of SLA at both the early and late stages, respectively.

5.1.2. The relationship between spindles and the early phase of SLA.

Ullman's Declarative-Procedural model (2001a, 2004, 2005) of SLA proposes that during the early phase of SLA declarative memory is important for memorizing word meaning and sound, and for acquiring and using grammar. Sleep spindles are important for the optimal consolidation of declarative memory. For example, spindle number and density have been shown to increase after learning a declarative memory task, and this increase is correlated with task performance (Clemens et al., 2005; Gais et al., 2002; Schabus et al., 2004, 2008). When spindles are enhanced using transcranial alternating current, declarative memory performance is also enhanced (Marshall et al., 2006). In neuropsychological cases of decreased declarative memory capacity, spindle activity (number, duration, amplitude) is also reduced (for a review see, Lu & Göder, 2012). Here we show that there is an association between improved proficiency in language and increased spindle density from

early to late stages of SLA. This finding is consistent with the function of sleep spindles for declarative memory consolidation, and suggests that there is a specific period at the early phase of SLA (when declarative memory is most important), where sleep spindles may be involved in the consolidation of the second language.

5.1.3. The relationship between theta activity during rapid eye movements and the late phase of SLA.

While it is well-established that rapid eye movements support memory consolidation for cognitively complex procedural skills (see Fogel & Smith, 2011), why eye movements *per se* are important markers of this process remains to be answered. Ullman's Declarative-Procedural model of SLA (Ullman, 2001a, 2004, 2005) proposes that during the late phase of second language learning there is a shift from declarative to procedural memory systems for the acquisition and use of grammar. Memory for cognitively complex procedural skills (*i.e.*, Wff'n Proof Task (Smith, 1993; Smith & Fazekas, 1997; Smith & Weeden, 1990); Tower of Hanoi (Conway & Smith, 1994; Smith et al., 2004); and mirror tracing task (Fogel et al., 2007; Plihal & Born, 1997; Smith et al., 2004)) have been shown to be consolidated during REM sleep. The number and density of eye movements during REM have been found to be correlated with task performance improvements (Smith et al., 2004), and are considered a marker for the intensity of this memory function of REM sleep. Rapid eye movements are generated by rhythmic oscillations in the ponto-geniculo-occipital circuit. Beyond that, the underlying associated neural activity that might link eye movements to memory processing remains a mystery. Contrary to our hypotheses, the current study did not identify any night-to-night changes in REM density during Late SLA, or any correlation between REM density and language proficiency. Instead, here we show for the first time, a learning related increase in EEG theta activity time-locked to eye movements during REM

sleep. Hippocampal theta activity predominates in REM sleep (Buzsaki, 2002), and is correlated with rapid eye movements, as well as PGO waves (Karashima et al., 2004, 2005, 2007). Hippocampal theta has been associated with memory consolidation, for example, during REM sleep rats show increases in theta after an avoidance task (Fogel et al., 2009). Furthermore, theta has been linked with long term potentiation, for example, LTP can be induced by stimulation patterns that mimic the theta rhythm (Larson et al., 1986), as well, the strength of LTP increases linearly with theta power (Maren et al., 1994). Lastly, theta has been associated with learning, for example, drugs which decrease theta power block learning (Givens & Olton, 1995) while drugs that promote the theta rhythm facilitate learning (Staubli & Fang Bo Xu, 1995; Staubli et al., 1994). The hippocampus shows extensive projections (and back-projections) to the cortex (see Miller, 2013), through which it is thought to induce theta activity (Klimesch, 1996). Together, this may suggest that rapid eye movements during REM sleep may be linked to theta production and may reflect underlying memory processing.

5.1.4. Hemispheric lateralization in SLA.

Whether language is lateralized, particularly in the context of learning a second language, has been a heated topic of debate within the field of linguistics (*i.e.*, see Paradis, 2000). Studies examining lateralization in SLA have investigated brain activity during behavioural tasks such as visual preference (Bentin, 1981), dichotic listening (Fabbro, 1992), and the dual attention task (Fabbro, 1992; Hall & Lambert, 1988). However, using behavioural tasks to assess hemispheric specialization for SLA is confounded by differences in memory constraints, the dependent measures used, practice effects and the comparison control groups (see Obler et al., 1982). The present study examined lateralization effects

across the course of SLA while controlling for some of these confounds (by examining sleep-related consolidation), as well as moderators including the manner of acquisition (both formal and informal training), and the stage of acquisition (repeated measures design across Early and Late SLA). The current study did not identify any evidence of lateralization (W1 compared to W2) for markers of sleep-related memory consolidation including sleep spindles or event-related power changes time-locked to rapid eye movements.

Past research examining hemispheric specialization during sleep-related consolidation across the course of an intensive second language course have suggested that there is a shift in hemispheric activity during REM sleep as participants gain proficiency in the second language (Hébert et al., 1992; Hébert & De Koninck, 1993, 1994). The directionality of this shift has been suggested to differ across participants (Hébert et al., 1992), or shift from left-hemispheric dominance to balanced hemispheric participation (Hébert & De Koninck, 1993, 1994). While the present study did not find evidence of lateralization, this is not to say that this relationship does not exist. Indirectly, the present study did find a correlation between improvements in French proficiency and sleep spindle density, as well as theta activation time-locked to rapid eye movements only for the left Wernicke's electrode site. This may suggest that the left hemisphere generally plays a larger role in memory consolidation for late-learned SLA; however, this would need to be investigated further. Furthermore, given the disagreement within the literature (see Hull & Vaid, 2007; Paradis, 2000), it is likely there are additional moderators (beyond age, language proficiency, and manner of learning) that may explain hemispheric representation of the second language that have yet to be identified.

5.2 Limitations of the current study.

The main limitation of the current pilot study was the small final sample size (N=8), and, which limited our ability to detect small to medium sized effects. We conducted a post-hoc sensitivity power analysis in G*Power (Faul et al., 2007). This analysis revealed that the current investigation was only able to detect large effect sizes (Cohen, 1988). Given the inability of the present study to detect small or medium sized effects, the null results reported here should be taken with caution. However, despite the small sample size, we were still able to extend on previous findings. In addition, the current study would be strengthened by comparing to a non-language learning control group. Importantly, we did have a post-course Follow-up overnight sleep recording, where sleep parameters should have returned to some baseline level in an extensive and powerful repeated measures design (involving up to 12 nights of polysomnography per individual). Nonetheless for this reason, the results should be interpreted with caution and considered proof-of-concept, as it cannot be conclusively determined if the observed results were due to some non-specific aspect of being enrolled in the course, or some other unknown factors occurring systematically over time.

5.3 Conclusions.

The present study revealed that those who had more sleep spindles during Early SLA improved more in French proficiency. This suggests that sleep spindles may contribute to memory consolidation for word meaning, sounds, and grammar during the early phase of SLA. Furthermore, theta activity time-locked to the peak of the eye movements during REM sleep was increased for Late SLA compared to Early SLA. The increase in theta activity time-locked to rapid eye movements in Late SLA was associated with greater improvements in French proficiency. This suggests that REM sleep is involved in consolidating grammar

during Late SLA, and more broadly, for the first time, provides preliminary evidence that theta activity may underlie the memory-related function of rapid eye movements. In summary, this research has implications for our understanding of how sleep-related markers of memory consolidation support learning, as well as expands our understanding of how second languages are acquired. In addition, these findings may contribute to our understanding of language impairments, as problems in language learning are associated with sleep disorders for both children and adults (see McGregor & Alper, 2015). Furthermore, given the proposed involvement of the declarative and procedural memory systems in the acquisition of a child's first language (Ullman, 2001a, 2001b, 2001c), the findings of the present research may be extended to our understanding of first language acquisition.

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Appendix A: Letter of Information

May 5, 1990.

Dear

I have been informed by the Centre for Second Language Learning that you are registered to take the French immersion course (Ecole Francaise d'Eté, starting June 25th) this summer at the University of Ottawa. I would like to offer you the opportunity to participate in an experiment conducted during this course.

I am an experimental psychologist involved in the study of sleep and dreams. In this context, I am studying the sleep pattern and the dreams of individuals in the process of intensive language learning. Students attending the "Ecole Francaise d'été" seem particularly well suited for this study.

Your participation would require sleeping in a "sleep laboratory" for 3 nights during the month of June, 4 nights during the course period and 2 nights in August, after the course. In addition you would be asked to keep a dream diary for the duration of the experiment. It is pertinent that only unilingual English individuals participate in this study.

For your participation you would receive $300. If necessary, your transportation and room and board before and after the course will also be paid for. This experiment will not interfere with your course (only nights would be spent in the lab) and should prove very interesting. In the past few years, a number of students have participated in this experiment and found it to be very interesting. Sleeping in a "sleep laboratory" is a new experience that is worth trying.

If you are interested and/or would like to have additional information please contact either Gilles Hébert, a doctoral student working in my laboratory or myself. We may be reached collect as of Monday, May 7 at one of the following numbers: from 9 a.m. to 5 p.m., ***-***-**** or ***-***-**** or in the evening I can be reached at ***-***-****. We hope to hear from you soon.

Sincerely yours,

Joseph De Koninck, Ph.D.
Gilles Hébert, Doctoral candidate

Appendix B: Telephone Interview and Screening Questions

ENTREVUE AU TELEPHONE

Name: _____ Age:_____ Sexe:___

Addresse:_____
_____
_____
tel #: _____

Sleep disorders: now: _____ in the past:_____

Medical disorders: _____

Allergies: _____

Medication: _____

Latéralité: _____

Other languages: _____

Other french courses: _____

_____

First course, when?: _____

Background: Mother:_____ Father: _____

Grandmother: _____ Grandfather: _____

Aunts: _____ Uncles: _____

Friends: _____ Summer jobs: _____
_____

Dates involved: June 8 to August 26 (approximately)

Are you willing to return at our cost before and after the course for two nights?: _____

notes : - 300 $
— don't study beforehand
— we arrange and pay train or bus
— room paid before and after course
— 20 $ per day for food before and after

questions : _____
_____
_____
_____

Appendix C: Description of the Minnesota Multiphasic Personality Inventory

This questionnaire is a self-report True-False inventory developed in the late 1930s by Starke R. Hathaway, and J. C. McKinley at the University of Minnesota. It is designed to assess personality traits as well as psychopathology on ten different scales: hypochondriasis, depression, hysteria, psychopathic deviate, paranoia, psychasthenia, schizophrenia, hypomania, masculinity-femininity, and social introversion.

Scale 1: Hypochondriasis. Designed to assess neuroticism around bodily functioning.

Scale 2: Depression. Designed to identify depression symptomology.

Scale 3: Hysteria. Designed to identify hysteria in stressful situations.

Scale 4: Psychopathic Deviate. Designed to identify amoral behaviour, social deviation, and lack of acceptance of authority.

Scale 5: Masculinity/Femininity. Designed to identify homosexual tendencies.

Scale 6: Paranoia. Designed to identify symptoms associated with paranoia including: suspiciousness, feelings of being persecuted, grandiosity, excessive sensitivity, and rigid attitudes.

Scale 7: Psychasthenia. Designed to identify compulsions, obsessions, and unreasonable fears.

Scale 8: Schizophrenia. Designed to identify schizophrenia symptomology.

Scale 9: Hypomania. Designed to identify elevated mood, accelerated speech, irritability, flight of ideas, and brief depression.

Scale 10: Social introversion. Designed to identify a tendency to withdraw from social contact.

In addition to the clinical scales- there are seven response scales: the L (lie scale), F (faking good, or faking bad scale), K (defensiveness scale), ? (cannot say scale), TRIN (true response inconsistency scale), VRIN (variable response inconsistency scale), and Fb (random answers scale).

Appendix D: Edinburgh Handedness Inventory

Edinburgh Handedness Inventory

Instructions: Please indicate your preferences in the use of hands in the following activities **by putting a check in the appropriate column**. Where the preference is so strong that you would never try to use the other hand, unless absolutely forced to, **put 2 checks**. If in any case you are really indifferent, **put a check in both columns**.

Some of the activities listed below require the use of both hands. In these cases, the part of the task, or object, for which hand preference is wanted is indicated in parentheses. Please try and answer all of the questions, and only leave a blank if you have no experience at all with the object or task.

Activity	Left	Right
1. Writing		
2. Drawing		
3. Throwing		
4. Scissors		
5. Toothbrush		
6. Knife (without fork)		
7. Spoon		
8. Broom (upper hand)		
9. Striking Match (match)		
10. Opening box (lid)		

For test administrator use only-

SubID: _____ Date: _____

TOTAL SCORE (add up all checks in each column)**:** _____

Cumulative total (left + right) _____

Difference (right – left) _____

Index [(difference/cumulative total)*100] _____

Appendix E: A Description of the State-Trait Anxiety Inventory

The State-Trait Anxiety Inventory is a self-report measure consisting of 20 items to assess trait anxiety and 20 items to assess state anxiety. State anxiety is defined as the momentary emotional status resulting from situational variables (i.e., “I am tense”; “I feel calm”), while trait anxiety (i.e., “I worry too much over something that really doesn’t matter”, “I am a steady person”) represents a predisposition to anxiety. Items are answered on a 4-point scale ranging from “Almost Never” to “Almost Always”. A higher score indicates a greater level of anxiety. Internal consistency ranges from .86 to .95; while test-retest reliability ranges from .65 to .75 (Spielberger et al., 1983).

Appendix F: Description of the 16 Personality Factor Questionnaire

A 164 item questionnaire designed to evaluate personality traits. Each item is answered on a five-point scale (“disagree”, “slightly disagree”, “neither agree nor disagree”, “slightly agree”, “agree”) with each end of the scale having a meaningful definition. The questionnaire consists of 16 primary personality scales, five global personality scales, and three validity scales. The 16 primary scales include: warmth, reasoning, emotional stability, dominance, liveliness, rule-consciousness, social boldness, sensitivity, vigilance, abstractedness, privateness, apprehension, openness to change, self-reliance, perfectionism, and tension. The global factors include: introversion/extroversion, low anxiety/high anxiety, receptivity/tough-mindedness, accommodation/independence, and lack of restraint/self-control. The three validity scales are the bi-polar impression management scale, the acquiescence scale, and the infrequency scale.

Appendix G: Beck Depression Inventory

A (Mood)

0 I do not feel sad
1 I feel blue or sad
2a I am blue or sad all the time and I can't snap out of it
2b I am so sad or unhappy that it is very painful
3 I am so sad or unhappy that I can't stand it

B (Pessimism)

0 I am not particularly pessimistic or discouraged about the future
la I feel discouraged about the future
2a I feel I have nothing to look forward to
2b I feel that I won't ever get over my troubles
3 I feel that the future is hopeless and that things cannot improve

C (Sense of Failure)

0 I do not feel like a failure
1 I feel I have failed more than the average person
2a I feel I have accomplished very little that is worthwhile or that means any¬ thing
2b As I look back on my life all I can see is a lot of failures
3 I feel I am a complete failure as a person (parent, husband, wife)

D (Lack of Satisfaction)

0 I am not particularly dissatisfied
la I feel bored most of the time
lb I don't enjoy things the way I used to
2 I don't get satisfaction out of anything any more
3 I am dissatisfied with everything

E (Guilty Feeling)

0 I don't feel particularly guilty

1 I feel bad or unworthy a good part of the time
2a I feel quite guilty
2a I feel bad or unworthy practically all the time now
3 I feel as though I am very bad or worthless

F (Sense of Punishment)

0 I don't feel I am being punished
1 I have a feeling that something bad may happen to me
2 I feel I am being punished or will be punished
3a I feel I deserve to be punished
3b I want to be punished

G (Self Hate)

0 I don't feel disappointed in myself
la I am disappointed in myself
lb I don't like myself
2 I am disgusted with myself
3 I hate myself

H (Self Accusations)

0 I don't feel I am any worse than any¬ body else
1 I am very critical of myself for my weaknesses or mistakes
2a I blame myself for everything that goes wrong
2b I feel I have many bad faults

I (Self-punitive Wishes)

0 I don't have any thoughts of harming myself
1 I have thoughts of harming myself but I would not carry them out
2a I feel I would be better off dead
2b I have definite plans about commit¬ ting suicide
2c I feel my family would be better off if I were dead
3 I would kill myself if I could

J (Crying Spells)

0 I don't cry any more than usual

1 I cry more now than I used to

2 I cry all the time now. I can't stop it

3 I used to be able to cry but now I can't cry at all even though I want to

(Irritability)

0 I am no more irritated now than I ever am

1 I get annoyed or irritated more easily than I used to

2 I feel irritated all the time

3 I don't get irritated at all at the things that used to irritate me

L (Social Withdrawal)

0 I have not lost interest in other people

1 I am less interested in other people now than I used to be

2 I have lost most of my interest in other people and have little feeling for them

3 I have lost all my interest in other people and don't care about them at all

M (Indecisiveness)

0 I make decisions about as well as ever

1 I am less sure of myself now and try to put off making decisions

2 I can't make decisions any more with¬ out help

3 I can't make any decisions at all any more

N (Body Image)

0 I don't feel I look any worse than I used to

1 I am worried that I am looking old or unattractive

2 I feel that there are permanent changes in my appearance and they make me look unattractive

3 I feel that I am ugly or repulsive

looking

O (Work Inhibition)

0 I can work about as well as before

la It takes extra effort to get started at doing something

lb I don't work as well as I used to

2 I have to push myself very hard to do anything

3 I can't do any work at all

P (Sleep Disturbance)

0 I can sleep as well as usual

1 I wake up more tired in the morning than I used to

2 I wake up 1-2 hours earlier than usual and find it hard to get back to sleep

3 I wake up early every day and can't get more than 5 hours sleep

Q (Fatigability)

0 I don't get any more tired than usual

1 I get tired more easily than I used to

2 I get tired from doing anything

3 I get too tired to do anything

R (Loss of Appetite)

0 My appetite is no worse than usual

1 My appetite is not as good as it used to be

2 My appetite is much worse now

3 I have no appetite at all any more

S (Weight Loss)

0 I haven't lost much weight, if any, lately

1 I have lost more than 5 pounds

2 I have lost more than 10 pounds

3 I have lost more than 15 pounds

T (Somatic Preoccupation)

0 I am no more concerned about my health than usual

1 I am concerned about aches and pains or upset stomach or constipation or other unpleasant feelings in my body

2 I am so concerned with how I feel or what I feel that it's hard to think of much else

3 I am completely absorbed in what I feel

U (Loss of Libido)

0 I have not noticed any recent change in my interest in sex

1 I am less interested in sex than I used to be

2 I am much less interested in sex now

3 I have lost interest in sex completely

Appendix H: Informed Consent Form

Consent Form for the
Second Language Learners

Dr. Joseph De Koninck. Professor of Psychology at the University of Ottawa, is conducting a research in order to measure the sleep characteristics of those enrolled in an intensive second language course.

Outline of the study

-The Sleep Research Laboratory is located in room 424 of Montpetit Hall at the University of Ottawa.
-The study consists of having each participant sleep 13 nights in the laboratory, throughout the summertime, and in four series of consecutive nights (4 nights, 3 nights, 3 nights, 3 nights).
-Individuals participating in the research are assured complete confidentiality regarding the physiological and psychological measures obtained during the study.
-Electrodes will be installed before each night spent in the laboratory. These electrodes are applied externally to the skin and may, for some individuals, cause minor irritation to the skin.
-Each participant will have a private room and his/her comfort will be respected as much as possible (i.e. pillow, room temperature, private bathroom & shower provided).
-At all times during the night, a research assistant will be in the laboratory. If for any reason you wish to communicate with the assistant on call, you may do so via an intercom system installed in the bedroom.
-The participant's sleep positions and body motility will be recorded during the nights, with the use of a video camera.

Additional information

-It is our opinion, based on prior sleep research, that there is no health danger whatsoever for the participant. Nevertheless, if your past health history suggests that any type of complication could occur because of your participation in the study, the experimenter should be consulted prior to the beginning of the research.
-If requested by the participant, a research assistant of the same sex will be provided
-Each participant will be renumerated approximately 20$ per night spent in the laboratory, for a total of $300.
-An additional 50$ will be offered to the participant if he/she completes a dream-diary for the duration of the study
-The participant may withdraw from the present study at any time, even after having signed the consent form.
-All collected data will be kept confidential, and any published data will respect anonimity.
-The participant will need to devote a certain amount of time every morning to his/her personal hygiene.
-A feedback session will be scheduled after the completion of the study (if desired by the participant), in order to allow the experimenter to answer any questions, as well as offer a more detailed rationale of the study.

I have explained the nature of the research to the participant, and believe that he/she has understood it.

_____	_____	_____
Participant’s name	Participant's signature	Name of investigator

Appendix I: Course Program of Events

Attestation

École française d'été (1989)

—session: du 26 juin au 4 août 1989

Au sujet de l'étudiant(e) _____
Numéro: _____

A qui de droit,

Le cours de cote FLS 1 65 IA est un cours di immersion en français langue seconde et se donne tous les étés durant 6 semaines (total: 150 heures) par l' Institut des langues secondes de l'Université d'Ottava.

Le programme pour l'été 1989 est le suivant:

Cours de l'avant-midi: 9h00 - 12h00 (total: 90 heures) apprentissage du français parlé et écrit en classe et au laboratoire, avec méthodes audio-visuelles. Pratique individuelle au Centre de ressources pour les etudiants.

Cours de l'après-midi: -13h00- 16h00 (total 60 heures) apprentissage du français sous son aspect culturel dans le cadre de séminaires et d'ateliers sur la presse, la chanson, le cinema, les jeux, etc.

Activités du soir et des fins de semaine:
19h00 -24h00 environ trois activités par semaine dans le but de faire utiliser le français d'ordre social (sports, rencontres avec francophones) ou culturel (artistes, spectacles, excursions).

Les cours de cote FLS 165 IA ont une valeur de six crédits à l'Université d'Ottawa. Les étudiants sont soumis à un test de classement au début et sont groupés selon leur niveau de connaissance du français langue seconde.

_____ a été classé(e) au niveau _____
et à la fin du cours a obtenu la note _____

Ledirecteur
de l'École françaised'été 1989,

Jean-Guy Giroux

GROUPE 1: niveau élémentaire

PROFESSEUR : Robert Paquette

RÉSUME DU CONTENU:

-les expressions de salutation et de présentation: contextes formels et informels
-la phonétique du français, l'alphabet, la ponctuation, les chiffres, le calcul.
-les pronoms sujets
-les verbes être et avoir
-la négation
-les formes interrogatives: n'est-ce pas ?
est-ce que?
par inversion
par variation d'intonation
-le genre et le nombre des adjectifs et des noms
-les expressions descriptives de l'environnement physique
-les expressions et les consignes d'orientation
-qu' est-ce que c'est?-les objets communs de la salle de classe, des types d'habitation et de la maison.
-les articles indéfinis
-I 'expression "il y a"
-les prépositions de lieu et les expressions locatives
-la place des adjectifs
-l 'impératif
-le verbe faire
-l 'indicatif présent des verbes en -er, -ir et -re
-les adverbes "rarement, parfois, beaucoup, souvent et toujours"
-les formes orthographiques exceptionnelles de certains verbes au présent
-les expressions de préférence
-le verbe aller
-aller- prépositions
-les adverbesinterrogatifs "où, quand, coment et pourquoi"
-le futur proche
-les adjectifs interrogatifs "quel..."
-les jours, les mois, les saisons, la date
-les adjectifs démonstratifs
-la possession et les adjectifs possessifs
-la famille
-les verbes irréguliers en -ir
-les verbes "vouloir, pouvoir et devoir"

LE LABORATOIRE: il y a eu trois sessions d'une heure chacune par semaine au labo(de groupe)et chaque étudiant • devait faire une heure de laboratoire individuel par jour.
Les programes de laboratoire utilisés étaient:
Accent on Accent, C. Champagne et J. Bourdages
Improving French Pronunciation, M. Léon
En bons termes,
Une série de cassettes préparées par le professeur sur les diverses expressions.

RÉSUME DU CONTENU SOCIAL ET CULTUREL :

Les étudiants étaient responsables des activités qui suivent:

Activité 1: Trouver un comerce dont le propriétaire est franco-canadien, préparer une entrevue, présenter 'entrevue à la classe et fai re une tournée du commerce avec la classe.

Activité 2: Choisir une chanson d'une liste donnée d'artistes et d'interprètes franco-canadiens, la préparer et la présenter à la classe.

Activité 3: Choisir un article en français et le présenter la classe.

Activité 4: Choisir une bande dessinée à teneur politique et • la présenter à la classe.

Activité 5: Faire une présentation la classe d'une série de scènes de restaurant, d'urgence (pol ice, pompiers, ambulance), d'une épicerie ou du marché, avec une présentation du vocabulaire et des expressions adéquates.

MATÉRIEL DIDACTIQUE UTILISË:

En bons termes
Invitation
French Structures in Review
Matériel didactique des cours FLS 1501 et 1502

Groupe 2: niveau élémentaire

Professeur: Suzanne Hotte

Objectifs généraux: amélioration à l'oral et à l'écrit de l'expression et de la compréhension.

Objectifs spécifiques: descriptions d'événements au present, au passé et au future

- brève introduction au conditionnel
- étude des semi-auxiliaires, des pronoms personnels complé— ments d'objets directs et indirects, des verbes pronominaux, vocabulaire de la maison, etc....

a) expression orale: expressions reliées aux - activités courantes—
   - expressions idiomatiques
   - renforcement du vocabulaire
   - jeux de rôle (au téléphone pour prendre un rendez—vous , pour réserver une table au restaurent ou une chambre à l'hôtel ...)
   - rencontres avec les francophones de L'ESS.

b) coznréhension orale:
   - film "Each et Bottine"
   - bandes sonores : En Bons Termes - exercises structureux, dictées, compréhension de l'oral
   - monologues pris dans Plans de conversation niveau débutant, niveau intermédiaire
   - chansons (analyse du contenu) exemple : Je voudrais voir la mer de Kichel Rivard
   - présentations faites par les étudiants
   - discussions et questions suite à ces présentations

c) expression écrite
   - exercices structuraux — compositions — dialogues

d) compréhension écrite
   - ecploitations de petits textes pris dans En Bons Termes

Manuel utilize En Bons Termes (Cahier de Laboratoire)

Groupe 3 : niveau intermédiaire

Professeure: Anne Boland

Matériel didactique:

Corbeil, R. & Thérien, C.	Êtes-vous en bonne santé?
Dieteker, S.	En bonne forme: révision de grammaire francaise
Mailhot, C.	2.000 expressions françaises pratiques et utiles
Parmentier, M. & Potvin, D.	En bons termes: manuel de laboratoire

Contenu gramatical:

- Conjugaison et emploi des verbes: présent, passé composé, passé imédlat, imparfait, futur simple, futur proche, impératif, conditionnel présent.
- Les pronoms et adjectifs.
- La négation, l'interrogation.
- Les verbes réflexifs.
- Vocabulaire et expressions françaises.

Travail de Laboratoire: 1 heure par semaine

- Exercices structuraux et de phonétique.
- Exercices de compréhension auditive.

Exploitations de situations concrètes:

- Le magasinage
- La santé
- L'éducation au Québec
- La famille

Méthodes:

- Présentation du matériel gramatlcal et lexical.
- Exercices oraux et écrits.
- Exercices de compréhension auditive.
- Lectures et dictées.
- Compositions.
- Discussions et débats.
- Présentations.
- Échanges hebdomadaires avec les étudiants en ESS.
- Laboratoire.
- Films.

Groupe 4 : niveau intermédiaire

Professeur : Marcel Painchaud

Objectifs du cours:
- Favoriser l'expression orale.
- Développer la pronunciation et L'intonation propres à la langue française.
- Faciliter les communications avec les Francophones de méme niveau.

Activités:
- lecture à haute voix
- Dialogues
- Entrevues sous forme de question/réponse
- Dictée
- Exercices d'écoute
- Composition

Evalutation
- 4 tests (1 par semaine) (60%)
- un examen final (30%)
- participation (10 %)

Total : 100%

Matériel

Le Français langue seconde par objectifs Niveau 4, Anne-Marie Connolly

Le quotidian Le Droit

Dépliants touristiques

Cassettes de chansons

Photocopies d'exercises

Groupe 5: niveau intermédiaire fort

PROFESSEURE: Francine Carbon

Manuel: Berlitz "French for travellers", completer par des textes et exercices emprüntës à différents manuels.

Contenu grammatical: Révision et approfondissement de tous les temps de verbes (à l'exception des temps littéraires), les verbes réflexifs, les verbes et expressions verbales suivis des prépositions de /à /Ø,, les pronoms compléments, les pronoms relatifs, les pronoms indéfinis, la négation, les adjectifs, les adverbes, les expressions de temps, l'ordre syntaxique.

Outils langagiers: l'expression corporelle, l'intonation, la liaison, différents accents français, l'argot et les expressions familières, les expressions idiomatiques, comment exprimer une opinion, un accord, un désaccord.

Contenu fonctionnel:

A/ Mise en pratique orale et discussion:
Nos valeurs/Economiser,le pour et le contre/ La nourriture, la restauration et la gastronomie française/ La recherche d'un logement/ Les voyages/ L'orientation dans une ville.

B/ Langue écrite: la correspondance
courts messages/ cartes postales/ correspondance familière/ correspondance d'affaires/ le curriculum vitae.

Contenu socio-culturel, jeux:

-Histoire: La révolution tranquille au Québec et la crise d'octobre 1970
-Audition de chansons françaises et québécoises.
-Petit déjeuner avec "CBOF Bonjour" (Radio Canada).
-A l'occasion du 14 juillet: déjeuner dans le parc avec spécialités françaises.
-Visite guidée au Musée des Civilisations (Hull)
-Echanges socio-culturels avec les étudiants du groupe 5 du ESS (2 heures par semaine).

GROUPE 6 : ..niveau intermédiaire fort
PROFESSEURE: Monique Pépin

L'accent a été mis principalement sur l'amélioration de la compréhension auditive et de l'expression orale. On a également travaillé à approfondir certains points grammaticaux. L'acquisition du vocabulaire pertinent aux diverses situations de communication travaillées en classe était. en outre un objectif important.

COMPREHENSION AUDITIVE ET EXPRESSION ORALE
Les divers exercices de compréhension et expression orale visaient à aider les étudiants à fonctionner dans des situations qui leur sont familières : se présenter, faire connaissance (bar, café, classe, université), s'informer (spectacles, restaurant, sur la rue, magasins), exprimer ses sentiments, ses opinions (expériences personnelles, spectacles, voyages, cours de langue, sujets d'actualité), informer (directions, activités, sports pratiqués), raconter, décrire, faire des réservations (restaurant, spectacle, avion, train), prendre rendez—vous.

Les étudiants ont également fait deux présentations orales et, dans le cadre d'échanges avec leurs condisciples du groupe 6 (ESS), ils ont travaillé à préparer et présenter un théâtre bilingue.

GRAMMAIRE
Les points suivants ont été en ce qui a trait à la grammaire:

- c'est, ce sont / il est, ils sont
- place des adjectifs
- expressions de temps
- temps du passé
- subjonctif
- condition

Bien entendu, au fur et à mesure des besoins des étudiants au cours des activités de compréhesion auditive et d'expression orale, les explications grammaticales nécessaires ont été données et des exer-

COMPREHENSION DE L'ECRIT

Les étudiants ont eu aussi l'occasion de développer cette compétence grâce à des lectures préparatoires à leurs présentations orales en classe ainsi qu'à des lectures personnelles au Centre de Ressources de l'Institut. En outre, divers textes écrits ont été utilisés comme point de départ d'activités de communication orale.

CONTENU CULTUREL

Grâce à des discussions, l'étude de quelques chansons, le visionnement de films et la lecture d'articles de revues québécoises et françaises, les étudiants ont été sensibilisés à divers aspects de "l'autre culture". Mais surtout, le travail d'équipe réalisé conjointement avec les étudiants francophones (groupe 6, ESS) , leur a pemis d'acquérir une connaissance "vécue" des particularités des jeunes francophones.

MATERIEL DIDACTIQUE

Voici une liste des principaux outils didactiques utilisés:
Nouveaux exercices de grammaire et Exercices de perfectionnement de de Salins et Dupré La Tour (grammaire),
Communication Plus 2 et 3 (compréhension auditive)
Répertoire de documents authentiques Laval (comp. aud.)
Cartes sur table 2 (comp. aud. et grammaire)
Documents de compréhension (ILS) 1703 et 1704) (comp. aud.)
Contextes for French Communication (comp. aud. et expression orale)

AUTO-APPRENTISSAGE

Les étudiants ont eu la possibilité de travailler à leurs objectifs personnels au Centre de ressources tels que perçus par eux-mêmes ou conseillés par moi selon les faiblesses constatées en classe. De plus, des exercices ont été proposés aux étudiants intéressés.

LABORATOIRE

Les étudiants ont travaillé au laboratoire 2 heures par semaine; mis sur la compréhension auditive.

GROUPE 7 - Niveau avancé

PROFESSEURE: Christiane Thérien

Objectifs généraux: amélioration, à l'oral et à l'écrit, de l'expression et de la compréhension.

Oblectifs spécifiques:

a) expression orale: description d'événements passés, présents et futurs
description de situations hypothétiques
expressions de sentiments, d'ordre, d'opinion
expressions idiomatiques
exercices/rythme/intonation/chute du "e" muet
travail de vocabulaire
jeux de rôle
rencontres avec les francophones de l'English Summer School
présentations Individuelles

b) compréhension orale:

documents audio-visuels (film, bandes sonores)
laboratoire (1 heure/semaine)
chansons (analyse du contenu sémantique et syntaxique, études de différents phénomènes de prononciation)
utilisation en classe d'enregistrements d'entrevues préparées par les étudiants en collaboration avec des francophones/étude de phénomènes linguistiques

c) expression écrite:

compositions sur sujets abordés en classe
compte rendu de la recherche hebdomadaire d'une heure au Centre de ressources

d) compréhension écrite:

exploitation de différentes stratégies de lecture
compte rendu de lecture d'articles

Manuel utilisé: Du bout de la lan ue au bout des doigts

Groupe 8: Niveau avancé

Prof.: R. Chiasson

Description du cours

Ce cours permet aux étudiant/es de surmonter les difficultés de compréhension et d 'expression en français oral et écrit.

Objectifs

Compréhension de l'oral: —repérer 1 'essentiel d 'un message enregistré
—résumer avec précision les idées principales d 'une entrevue
—donner une suite logique à une histoire racontée
—faire une synthèse des thèmes principaux d 'une d iscussion entre deux ou plusieurs individus
—analysez et commenter les opinions présentées lors d 'une entrevue ou d'une présentation orale

Matériel utilisé : —exercices préparés par Christiane Thérien et Renée Corbell de l'Institut des langues secondes de l'Université d'Ottawa
—exercices divers tirés des cahiers de la série Franca is parlé, de l'Université McGill
—documents authentiques : reportages faits à la radio et à la télévision

Compréhension de l'écrit:—repérer l'essentiel d 'un message écrit
—compléter un texte l'aide d tune liste de mots de vocabulaire
—faire ressortir les idées principales d'un message écrit
—identifier le but d 'un message écrit

Matériel utilisé: —exercices préparés par Christiane Thérien et Renée CorbeiI de l'Institut des langues secondes de l'Université d'Ottawa
—exercices tires de la série Français parlé de l'Université McGill

SEMINAIRE A: jeux

Professeur: B. Le Blanc

1) *Les objectifs*: A partin de countes activités de communication, les apprenants seront amenés à utiliser la langue de façon spontanée et moins contraignante qu'en sale de cours. Le but premier des activités sera done la communication et le second, non moins important, la revision des notions lexicales, grammaticales et/ou fonctionnelles acquises en salle de classe. Il est entendu que je maintiendrai un contact avec le professeur du matin afin de m'assurer que les activités conviennent aux étudiants.

2) *La structure du cours*: Chaque période de cours comprendra trois activités de longueur variée faisant appel à diverses habilités et à différents objectifs.
Le travail en sous-groupes sena privilégié afin de mieux satisfaire aux lesions des apprenants.

3) *L'évalutation*: L'étudiant devra preparer lui-méme une activité qu'il deura dinigen en salle de classe. L'évaluation se fera en fontion de son habilité à definin les objectifs de son activité et à en contróler sa realization. Il va sans dire que les strategies de communication joueront un grand nóle dans la definition et la realization des objectifs de l'activité et qu'elles seront par consequent, favorallement considérées dans l'évaluation globale de l'activité et qu'elles seront, par consequent, favorallement considérées dans l'évaluation globale de l'activité

4) *Les livres*:

Alshulen, C., Corraine, C., *La communication par le jeu,* C.E.C. Montréal, 1987, 151p. .

Richlerich, R., Suten, B., *Cartes sur table*, Hachette, Paris, 1981, 160 p. .

SEMINAIRE B : <u>Paroles et chansons</u>
Professeur : Aline Miller

Objectif	:	apprentissage de la langue à partir de l'écriture, de la chanson et du theater
Démarche	:	steelier d'écriture poétique et recitation des oeuvres Interaction musicale avec le "English Summer School" improvisations et mimes mises en situation dramatization de contes choisis
Répartition des sujets	:	1° semaine – poésie et chansons 2° semaine – art dramatique
Travaux	:	rédaction récitation interprétation
Note sur 10	:	5 pour les travaux 5 pour la participation

SEMINAIRE: “LA PRESSE”
PROFESSEUR: J.C. ROGER LANDRY

Ce séminaire n'a pas pris l'aspect d'un cours magistral; au contraire, les étudiants ont eu l’occasion de mettre la main à la pâte dans une série d’activités dont le but principal était de stimuler la conversation en langue seconde.

Sur le plan pratique, cela voulait dire:

- introduction du vocabulaire pertinent
- présentation d'articles par les étudiants
- synthèse des éditoriaux (présentation orale)
- visite au journal Le Droit
- exercices de recherche, faisant ressortir le vocabulaire
    - des nouvelles
    - des bandes dessinées
    - des annonces
    - des pages sportives, etc
- analyse d'articles d'intérêt humain, etc

L'intensité du travail en classe ainsi que. des devoirs allait de pair avec le riveau de compétence linguistique des étudiants. L'ensemble du séminaire étant axé sur l'oral,

Marlene et moi, nous avons organisé des rencontres entre les groupes anglophones et francophones. Le travail en equips a très bien marché et la réaction des étudiants été très positive.

L'assiduité des étudiants a été très bonne et leur motivation en classe s'est mainter.ue un très haut niveau tout au cours du séminaire.

J'aimerais saisir l'occasion pour féliciter les personnes responsables de l'organisation et de la réussite du prograrme, en particulier Messieurs Jean Guy Giroux et Bob Courchêne.

SEMINAIRE D: Cinéma

PROFESSEUR: Jean-Patrick Brodel

Le séminaire intitulé "Cinéma" offert dans le cadre de l 'école française d'été a suivi un parcours logique de l'expérience cinématographique.

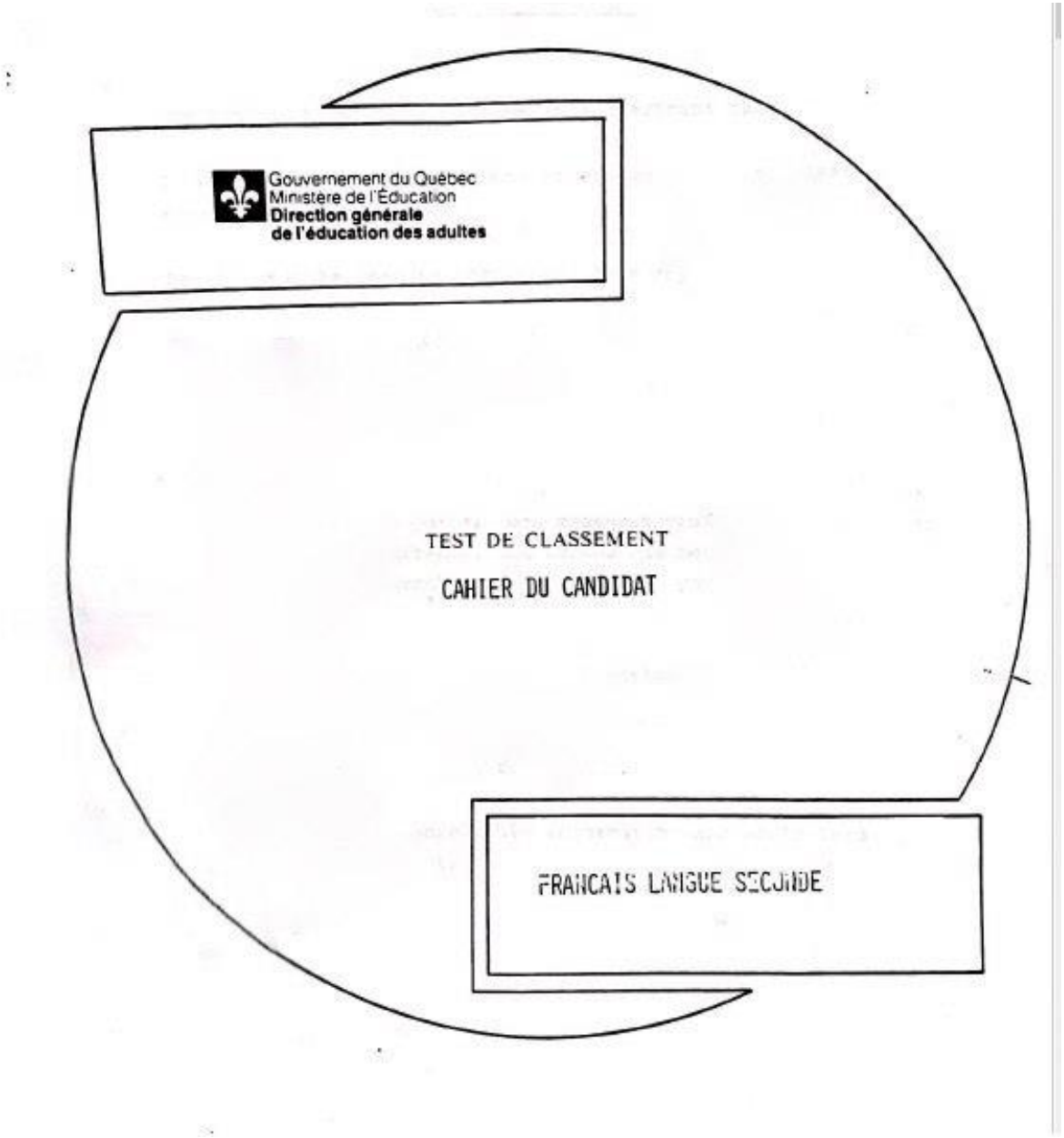
Dans ce survol de l'univers filmique, nous avons abordé, dans un premier tenps, les aspects extérieurs et intérieurs du film, suivant trois étapes distinctes qui sont la pré-production, le tournage et la post-production. Nous avons ainsi étudié les affiches de film, les titres, la composition du scénario, le traitement cinématographique (description des plans, mouvements de caméra, montage) et l'étude analytique du film du genre et de la catégorie ainsi que la critique de film. Chacun des points de ce cours a été illustré au moyen de documents écrits (courts textes théoriques, reproductions d'affiches,"story-board") ou visuels (extraits de films démontrant soit des plans soit des séquences contenant des éléments dramatiques sélectionnés, enfin, projection de film dans certains cas).

L'accent a été mis sur l'apprentissage et le développement du langage approprié à la description, à l'analyse et à la critique du film, en tenant compte de la diversité des niveaux.

Comme travail, les étudiants ont remis à la fin du séminaire, un rapport à la manière d'un résumé de cours et/ou une analyse et critique de film vu soit en classe soit au cinéma, ce, afin de leur faire récapituler l'ensemble des notions théoriques acquises, et de les inciter à utiliser le langage pratique qui leur a été enseigné dans ce séminaire.

Appendix J: The Ministère de l'Éducation Test de Classement

Document no:
905-002-03



CE DOCUMENT EST LA PROPRIÉTE DU MINISTERE DE L'ÉDUCATION.

VEUILLEZ LE REMETTRE AU SURVEILLANT LA FIN DU TEST.

TEST DE CIASSEMENT

The test you're going to take is a placement test.

It will help us determine the course which you are best prepared to enroll in.

It will not be used to reject you from any course.

We want you to feel relaxed about it.

Unless you have already mastered French rather well, you should not be surprised if you are unable to answer all the questions.

The test has three parts : one measures your ability to understand spoken French, the second one measures your ability to read French and the third one your ability to write in French.

You will be given the chance to understand what you are requested to do in each part.

We ask you never to guess the answer.

That would give us unreliable information and would lead to incorrect placement.

Have a good test

READING

In this part, we want to measure your ability to understand written French. This part has 12 questions, numbers 26 through 37.

The first type• of question consists in reading texts silently. One of the three sentences, A, B, or C, following each text relates best to the •text. Circle the letter identifying that sentence on your answer sheet.

For example:

Pierre est un joueur de football. Il joue avec l' équipe de la ville. Il s'entraine les lundi, mercredi et vendredi. Il joue une partie le dimanche.

A) Pierre joue au football le lundi.
B) Pierre a une équipe de football.
C) Pierre joue pour 1 'équipe de la ville.

the answer is (C). You should circle (C).

PAUSE.

We now begin.

- "Sylvie, faisonS une promenade la montagne.
- "Quand, Jacques? "
- "Cet apras—midi!"
- "D 'accord. Apportons nos raquettes, il y a beaucoup de neige."

26- A) Ils font une promenade dans la neige .

B) Il y a peu de neige sur la montagne.

C) Ils laissent leurs raquettes la maison.

Québec est une jolie ville canadienne-français. C' est un centre touristique important. On y trouve des rues étroites, des églises et des maisons historiques.En février, c' est le fameux Carnaval!

27 - A) Québec attire peu de touristes.

B) Québec compte une ancienne église.

C) . Québec organise une féte en hiver.

Jean est un jeune en santé et sport if. Le mois passé, il s’est blessé au genou pendant un match de foot— ball. Ses amis l'ont conduit ä l'höpital en automobile. Le médecin Iui a donné des béquilles pour marcher. Au— jourd'hui, Jean va bien. II peut courir, sauter, , danser et continuer ä jouer au football.

28- A) Jean s’est fait mal à l’hôpital.

B) Jean s’est fait mal au football

C) Jean s’est fait mal en automobile.

29- A) Jean a toujours pu faire du sport.

B) Jean marche avec des béquilles maintenant.

C) Jean peut faire du sport maintenant.

Test de ciassement

Dans votre dernier numéro, vous avez captivé non attention avec votre article sur Ia façon de protéger les enfants du quartier. C'est une initiative à imiter. Je considère que nos enfants ne sont pas en sécurité. Dites-moi ce que je dois faire et à qui il faut que je m'adresse pour organiser ce programme ici.

30- A) Elle a Iu un article qu 'eIle n'a pas aimé.
B) Elle a tout Iu sur les programmes de protection des enfants.
C) Elle est d 'accord avec I 'article.

31- A) Elle veut faire sa part pour la sécurité des enfants.
B) Elle trouve que Ies journaux ne font rien pour la sécurité des enfants.
C) Elle a l'information qu'il faut pour organiser un pro— grarnme de protection.

Depuis qu'elle est toute petite, Ginette pense à devenir comédienne. Pour elle, c 'est un métier plus intéressant que tous les autres. Méme si on Jui a dit que la concur— rence y est grande, méme s'il faut travailler beaucoup sans être jamais assuré de percer, rien ne la distrait de son orientation. En ce moment elle fait des démarches pour être admise dans une grande écoie de New—York. Si elle y parvenait, ce serait pour elle la chance de sa vie.

Elle travaillerait là-bas avec des maitres de calibre in— ternational et serait au courant de tout ce qui se fait dans son domaine. Elle affirme que dans cette école, on fait tout jouer aux éläves. Et c'est ce qui l'intéresse parti- culièrement, car elle veut prendre l 'expérience de plusieurs genres théätraux avant de se fixer. Ginette ne jure plus que par cette école d 'ou sont sorties de nornbreuses ve— dettes.

32- A) L' école de New-York prend des éléves de calibre inter— national.

B) L' école de New-York fait jouer aux étudiants les seules pieces qui les intéressent

C) L'école de New-York a formé des comédiens bien connus.

D) L'école de New-York forme des comédiens ' dans des genres limités.

33- A) Ginette croit qu'elle aurait avantage ä fréquenter l'école de New-York.

B) Ginette voudrait aller à New-York pour éviter la con— currence .

C) Si Ginette n 'est pas admise à cette école, e lle s 'orien— tera vers un autre métier.

D) Ginette espère devenir grande comédienne sans aller à New-York.

Test de classement

J' ai eu une vieille tante qui stappelait Eglantine. Ce nom, qu'elle avait reçu sa naissance, s jest révélé par la suite une prédestination; l'amour de ma tante pour les fleurs ne s’est jamais démenti. Plusieurs fois, pendant sa jeunesse, elle avait fait école buissonniäre. Et cela, sans autre raison que celle de vouloir admirer les fleurs des champs . Ses parents, bien sūr, la punissaient à chaque fois, mais à chaque fois elle recommençait. C'était plus fort qu'elle. En cinquième année, ses notes étaient si basses que ses pa— rents avaient décidé de la retirer de l'école. Elle devrait à l’avenir rester la maison pour aider sa -mère. Son amour pour les fleurs n' avait pas -cessé pour autant. Elle s’était occupée de la maison familiale en la transformant en véri— table jardin. Tout le monde trouvait ça beau mais quelque peu encombrant. On l’accusait souvent de préférer les fleurs aux hommes. Ce qui était vrai. A dix—huit ans -ses parents avaient voulu la marier à un jeune homme de bonne famille. Il avait quitté Eglantine après quelques semaines de fréquen— tation en disant qu’elle ne parlait que des fleurs. La méme chose s’était produite avec les deux ou trois soupirants suivants. A 97 ans, quand elle est morte, elle n 'était tou— jours pas mariée mais elle nous a légué un immense jardin à la campagne. Ce jardin est encore aujourd'hui un paradis de formes, de couleurs et d'odeurs!

34 – Eglantine a dû quitter l'école tôt:

A) pour aider sa mère malade.

B) pour suivre un cours spécialisé.

C) parce que ses notes étaient trop mauvaises.

D) parce qu'elle dérangeait les autres en classe.

Numbers 35 through 37 inclusively consist in another type of question. You will read a short text in which a word is under lined. On your answer sheet, circle the letter A, B, C, or D which is equivalent to the underlined word, considering the context.

35 – L'alpinisme est un sport aussi passionnant que dangereux. Chaque pas vous procure une impression de Victoire. Et, rendu au sommet, la vision du monde qui attendait es tune experience unique qu'aucun alpiniste n'a jamais oubliée!

procure

A) donne

B) porte

C) remet

D) enlève

36 – Le panax ou ginseng pousse en Chine, en Corée et en Sibérie mais il existe un variété qui croît en Amérique du Nord. Le panax nécessite un sol humide, ombragé et riche en humus. La racine met de 5 à 7 se developer et à acquérir

ses principes actifs. Depuis toujours, partout où pousse le panax, les population l'ont tenu en très haute estime, que ce soit en Chine ou chez les Amérindiens.

ont tenu

A) ont pensé

B) ont placé

C) ont fixé

D) ont répandu

37 – Depuis plus de 20 ans, l'ancien millionnaire de Hampstead est l'objet d'enquêtes de la part des policiers canadiens chargés de la lutte au crime organisé. Mais, c'est la première fois que des accusations criminelles sont portées contre lui. La première véritable étude sur le crime orga nisé au Québec faite par la Commission d'Enquête Prévost en 1968 avait déjà identifié cet homme comme l'un des magnats de la pègre locale. On l'a qualifié un peu plus tard d'in touchable du milieu.

qualifié

A) rendu compétent

B) accpté

C) déploré

D) désigné du titre

WRITING

This part has 8 questions, numbers 38 through 45.

In this part, we will measure your ability to write French.

There are questions of different types in this part. Follow the specific directives given for each of them.

For numbers 38 through 40, circle (on your answer sheet) the letter identifying the correct form of the word that completes the sentence.

38 – Ne cherche pas tes factures d'essence, je les ai _____.

A) payés

B) payée

C) payer

D) payées

39 – Ils auraient mieux compris si tu leur _____ plus clairement.

A) expliquerais

B) aurais expliqué

C) avais expliqué

D) as expliqué

40 – Au moment où vous avez eu cet accident, votre police d'assurance _____ d'être valide.

A) cesserait

B) aurait cessé

C) avait cessé

D) cesse

Test de classement

On your answer sheet, make a sentence with the words given for numbers 41 through 43.

41 – beacoup – fait – neigé – Il – beau – cette – il – maintenant – a – mais semaine –

42 – a – lui – plâtre – quand – mal – Le – enlevé – lui – son – fait – médecin – il – a –

43 – finir – l' – reviennent – avant – ménage – école – voudrait – enfants – Elle – son – de – les – que –

44 – Put capital letters where required on your answer sheet.

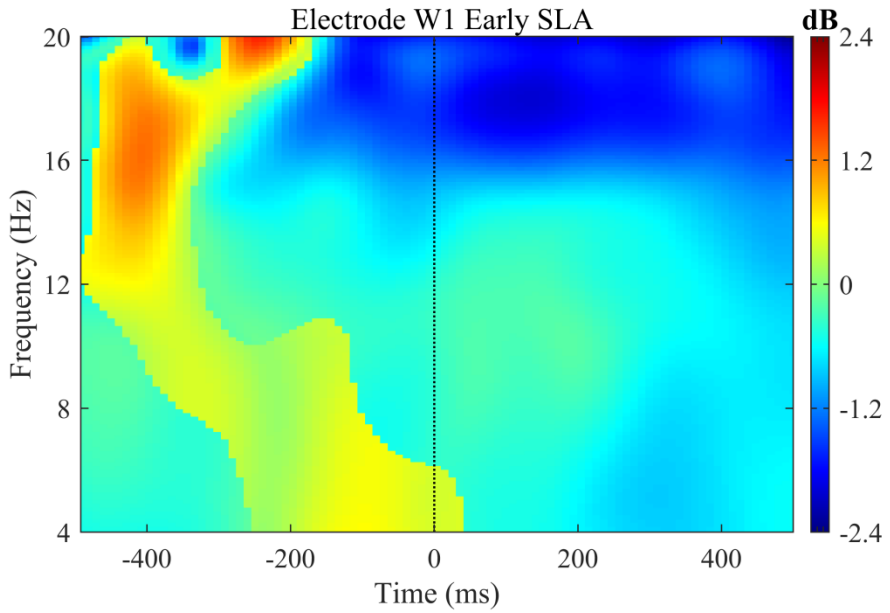
Mireille est une excellente photographe bien qu'elle n'ait jamais étudié la photographie elle a reçu sa première caméra vers l'âge de onze ans c'était lors d'une visite chez son grand-père elle a aujourd'hui 22 ans et on demand eses services de partout.

45 – Rewrite the following sentence as required on your answer sheet.

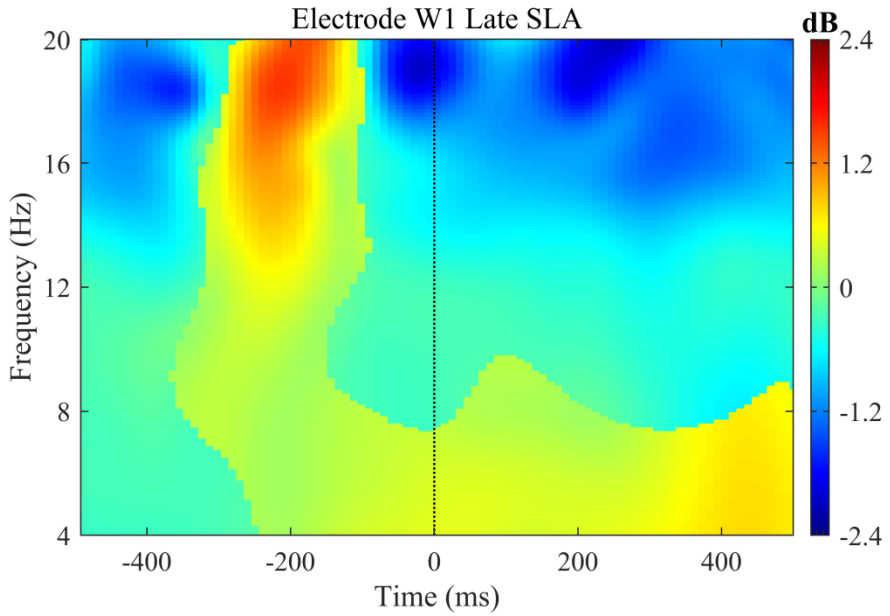
- "Dis-moi si c'est lui qui a fait cela."

Appendix K: ERSP Results

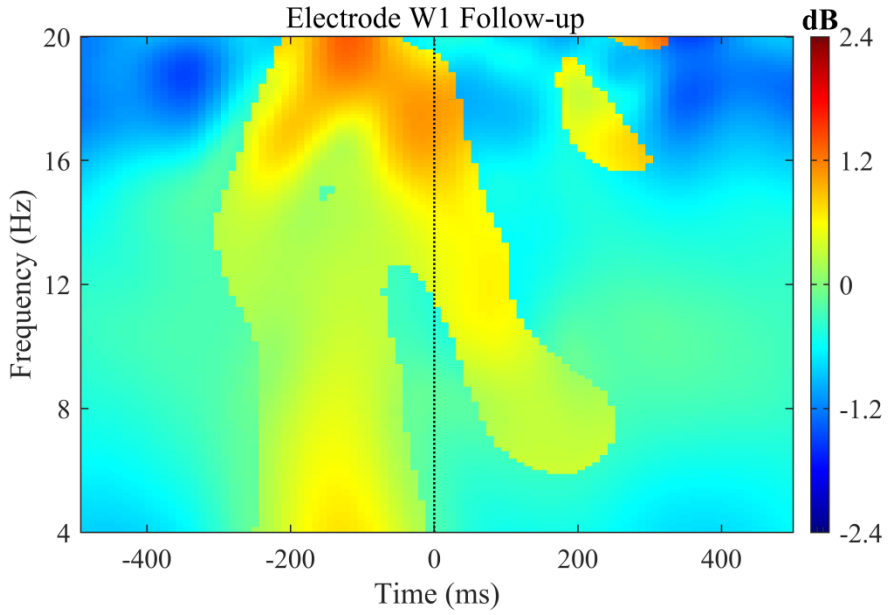
A



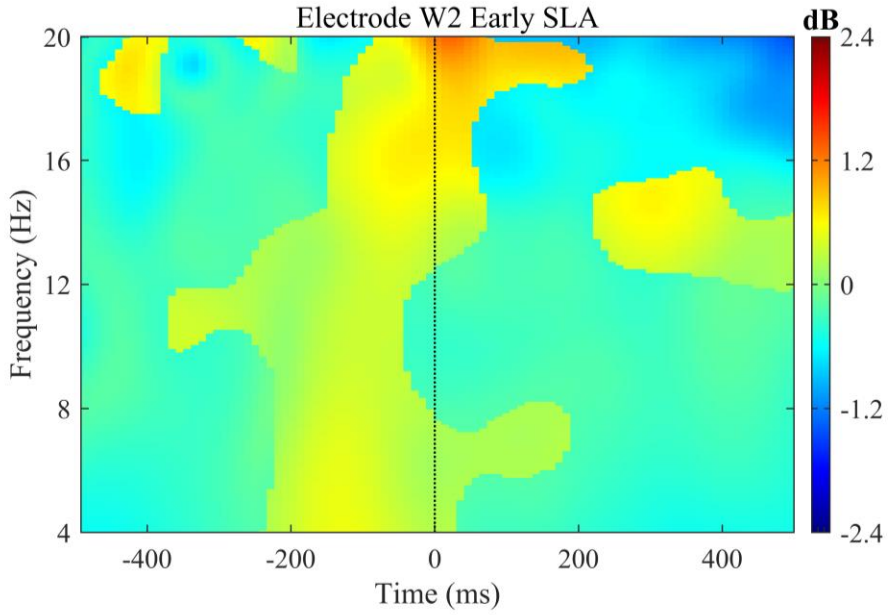
B



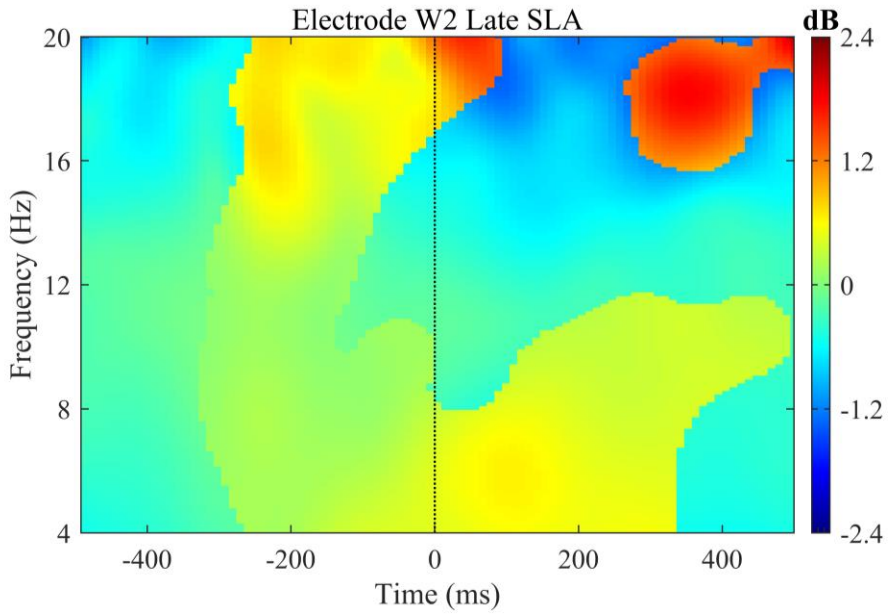
C


Electrode W1 Follow-up
dB
2.4
1.2
0
-1.2
-2.4
20
16
12
8
4
Frequency (Hz)
-400
-200
0
200
400
Time (ms)

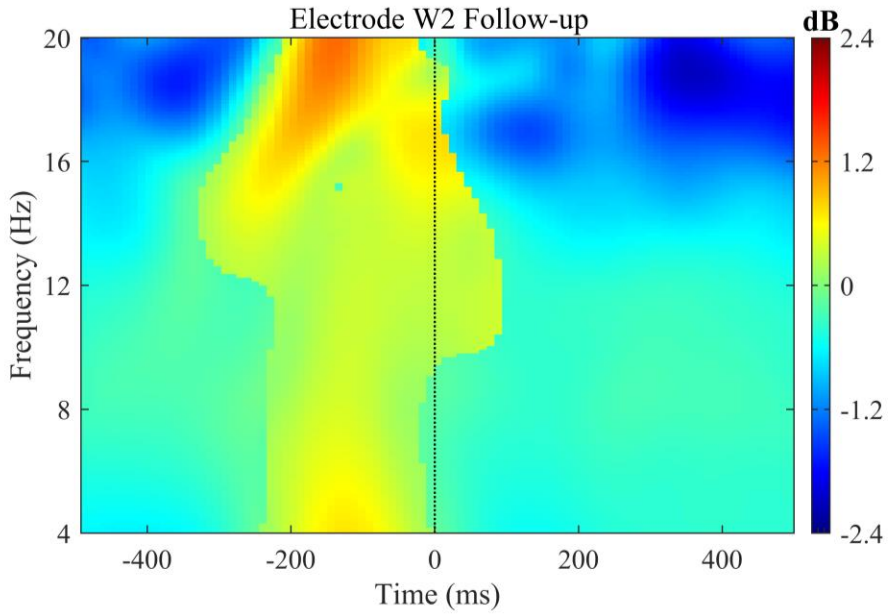
D


Electrode W2 Early SLA
dB
2.4
1.2
0
-1.2
-2.4
20
16
12
8
4
Frequency (Hz)
-400
-200
0
200
400
Time (ms)

E


Electrode W2 Late SLA
dB
2.4
1.2
0
-1.2
-2.4
20
16
12
8
4
Frequency (Hz)
-400
-200
0
200
400
Time (ms)

F


Electrode W2 Follow-up
dB
2.4
1.2
0
-1.2
-2.4
20
16
12
8
4
Frequency (Hz)
-400
-200
0
200
400
Time (ms)

CURRICULUM VITAE

Kristen Thompson

AREAS OF RESEARCH INTEREST

I am interested in studying the role of sleep-related markers of memory consolidation (including sleep spindles and rapid eye movements) in consolidation during second language acquisition.

EDUCATION

2018-2020 Masters – Experimental Psychology
Supervisor: Dr. Stuart Fogel

2012-2017 Bachelor of Arts, Psychology (Honours, First Class with Distinction)
Supervisor: Dr. John McDonald

THESIS & TITLE

MA (THM7999) Je voudrais parler français: Sleep spindles and REMs support learning a second language
University of Ottawa
Supervisor: Dr. Stuart Fogel

BA (PSYC 490 & PSYC499) Selection of multiple objects impairs subsequent visual search during the attentional blink
Simon Fraser University
Supervisor: Dr. John McDonald

AWARDS AND SCHOLARSHIPS

2020- Declined NSERC PGS-D, $63,000
2018- Declined Queen Elizabeth II Graduate (Master's) Research Scholarship, $10,800
2018- Declined NSERC CGS-M, $17,500
2018- Declined Ontario Graduate Scholarship, $15,000
2017 First Class with Distinction
2016 Simon Fraser Open Scholarship Recipient, Simon Fraser University, $1100/year
2015-2016 Ken Caple College Transfer Entrance Scholarship, Simon Fraser University, $3500/year
2014-2015 Dean’s List, Douglas College
2013-2014 Honour Roll, Douglas College

TEACHING EXPERIENCE

2020 Teaching Assistant, PSY 4327 Sleep and Dreams
2019 Teaching Assistant, PSY 4327 Sleep and Dreams

2019 Teaching Assistant, PSY 3377C Cognition
2018 Teaching Assistant, PSY 43911 Introduction to Neuroimaging
2018 Teaching Assistant, PSYC 201W Research Methods in Psychology
2017 Teaching Assistant, PSYC 386/PSYC 925 Lab in Behavioural Neuroscience/ Seminar in Cognitive Processes

PROFESSIONAL AND RESEARCH EXPERIENCE

2018- Present Research Assistant, Sleep Research Laboratory, University of Ottawa
2017-2018 Lab Coordinator, Human Electrophysiology Laboratory, Simon Fraser University
2017-2018 Residential Care Volunteer, Bailey House, CareLife, Ridge Meadows Hospital
2016-2018 Research Assistant, Attention and Memory Laboratory, Simon Fraser University
2017 Research Assistant, Social Science Camp, Autism and Developmental Disorders Lab, Simon Fraser University
2017 Student, York CVR-VISTA Vision Science Summer School, York University
2016-2017 Research Assistant, Human Electrophysiology Laboratory, Simon Fraser University

ADMINISTRATIVE EXPERIENCE

2018- 2019 First Year English Experimental Student Representative, Graduate Association of Students in Psychology, University of Ottawa

2017-2018 Social and Cognitive/Neural Area Editor, Undergraduate Journal of Psychology, Simon Fraser University

PUBLICATIONS

Smith, D., Fang, Z., **Thompson K**., & Fogel, S., (2020). Sleep and individual differences in intellectual abilities. *Current Opinions in Behavioural Sciences 33.* 126-131

CONFERENCE PRESENTATIONS

Lagroix, H.*****, Cork, T., Jankovic, N., Mudryk, E., Richardson, A., **Thompson, K.**, Di Lollo, V. & Spalek, T. (2018, May). The PR: An ERP index of the reactivation of spatially-specific memories. Vision Sciences Society Annual Meeting *St. Pete Beach*, Florida. *Journal of Vision*, *18*(10), 974-974.

Thompson, K. M.* & McDonald, J. J. (2017, August). *Visual Search is Delayed Following Enumeration of Multiple Visual Objects*. Paper presented at the meeting of the Cognitive Science Association for Interdisciplinary Learning *H*ood River, Oregon.

Thompson, K. M.* & McDonald, J. J. (2017, May). *Selection of Multiple Objects Impairs Subsequent Visual Search during the Attentional Blink.* Paper presented at the meeting of the NorthWest Cognition and Memory, *B*urnaby, British Columbia.

Thompson, K. M.* & McDonald, J. J. (2017, April). *Testing the Attentional Slot Hypothesis: an ERP Study on Visual Search in the Attentional Blink.* Paper presented at the meeting of the UVic Psi Chi: Making Waves Conference, Victoria, British Columbia.

Thompson, K. M.* & McDonald, J. J. (2017, March). *Testing the Attentional Slot Hypothesis: an ERP Study on Visual Search in the Attentional Blink*. Paper presented at the meeting of the Cognitive and Neural Sciences Area Seminar, Burnaby, British Columbia.

Lagroix, E. P., Cork, T.*****, Jankovic, N.*****, Mudryk, E.*****, Richardson, A.*****, **Thompson, K. M**.*, Di Lollo, V., & Spalek, T. M. (2017, May). *A New ERP Component Indexing the Reactivation of the Location of a Previous Target*. Poster presented at the meeting of the NorthWest Cognition and Memory, Burnaby, British Columbia.

INVITED COMMENTARIES

Thompson, K., Fang L. & Fogel, S. (2019, February). Simultaneous EEG-fMRI reveals neural substrates during sleep that support Fluid Intelligence. *Brain Products.*