EFFECTS OF AGE, NEED FOR COGNITION, AND COGNITIVE FATIGUE ON STATISTICAL LEARNING

by

Mark Dunlop

Department of Psychology

Submitted in Partial Fulfillment

of the requirements for the degree of

Bachelor of Arts

in

Honours Psychology

Faculty of Arts and Social Science

Huron University College

London, Canada

April 27, 2023

HURON UNIVERSITY COLLEGE

CERTIFICATE OF EXAMINATION

Advisor: Dr. Stephen Van Hedger

Reader: Dr. Christine Tsang

The thesis by:

Mark Dunlop

entitled:

Effects of Age, Need for Cognition, and Cognitive Fatigue on Statistical Learning

is accepted in partial fulfilment of the requirements for the degree of

Bachelor of Arts

in

Honours Psychology

__Type in Date of Submission___	____Type in Name of Departmental Chair__
Date	Chair of Department

Abstract

Previous research has suggested that increasing cognitive fatigue (CF) may facilitate implicit learning, including statistical learning (SL). The present study assessed whether this relationship between CF and SL is dependent on other factors known to interact with learning efficacy and susceptibility to CF – namely, age and the personality trait Need for Cognition (NFC). The study included 71 older participants (aged 55 years or older) and 95 younger participants (aged between 18 and 30). Participants were recruited into either a control group or a CF group, with all participants completing explicit and implicit assessments of SL. Results showed that SL occurred in both explicit and implicit forms. There were no significant differences in SL performance between age groups or conditions, although younger participants marginally outperformed older participants. There was, however, a significant difference between participants with high and low NFC scores, with high NFC participants having better performance in a SL task than those with low NFC scores. The study also found a borderline significant interaction effect between conditions and NFC in implicit SL. Participants with low NFC scores performed worse when fatigued compared to low NFC participants in the control condition, while high NFC participants had better performance when fatigued compared to high NFC participants in the control condition. Limitations and implications of the study are discussed.

Keywords: *age, need for cognition, statistical learning, cognitive depletion, implicit memory*

Acknowledgements

I would first like to thank my thesis advisor Dr. Stephen Van Hedger, for providing so much insight and support for this study. It would not have been possible without them. I would also like to thank my second reader Dr. Christine Tsang, as they were one of the first people who introduced me to Huron and they have always been willing to answer any question or concern I had. I must also thank Huron University College, and everyone that I met during me time there, as it has provided me such unique and rewarding experiences that it is impossible to convey in this short acknowledgment section. My time at Huron has changed how I view myself and the world around me. Finally, I want to thank my family for always being willing to help, even if what I asked them to do was confusing and seemed asinine at the time.

Table of Contents

Introduction

Why do infants and children learn languages faster than adults (Kennedy & Norman, 2005)? One influential theory is that adults use distinct learning mechanisms when acquiring language compared to infants and children. For instance, adults tend to acquire language through explicit instruction or intentional study approaches, which are generally mediated through a language with which the individual has expertise (Gu & Johnson, 1996; Rodríguez & Sadoski, 2002; van Hell & Mahn, 1997; Webb et al., 2020). In contrast, infants and children tend to acquire language through more implicit learning mechanisms, which can operate outside of conscious awareness and involve general pattern extraction from linguistic input (Perruchet, & Pacton, 2006).

The predominant implicit learning mechanism that has been discussed in the context of language learning is statistical learning (SL; e.g., see Romberg & Saffran, 2010 for a review). SL was first reported by Saffran et al. (1996), where it was discovered that infants could learn to extract patterns from novel speech sequences if the sound had meaningful statistical regularities (i.e., the probability of hearing a given sound was related to the previous sound(s) heard). In real-world contexts, SL is thought to facilitate the understanding of word boundaries. To illustrate this point, consider the example of learning the word 'baby' through statistical regularities. 'Baby' is often surrounded by many other words, (e.g., 'cute,' 'happy,' and 'tired') but from a statistical perspective, 'ba' is always followed by 'by' in the context of the word 'baby.' Thus, through learning these regularities, infants perceptually group 'baby' together as a word and not the syllables that cross word boundaries (e.g., 'te-ba,' 'py-ba,' and 'red-ba' from the previous examples of 'cute baby,' happy baby,' and 'tired baby,' respectively), as these are more variable and thus encountered less frequently. Critically, as mentioned earlier, this form of SL in infants is thought to be driven by implicit processes, as SL in infants occurs without instruction or intention (Perruchet, & Pacton, 2006). This implicit memory, or nondeclarative memory, is mediated by basal ganglia, cerebellar, and neocortical structures, as well as parts of the prefrontal cortex (e.g., Broca's area; de Vries et al., 2010; Uddén et al., 2008; Ullman, 2006), and includes the acquisition of a heterogeneity of skills, habits, and procedures. Implicit memory, unlike other types of memory, is also theorized to be independent of working memory and directed attention (Yang et al., 2020; Batterink & Paller, 2019).

In contrast to infants and children, adults tend to use more explicit mechanisms when learning new languages (Gu & Johnson, 1996; Rodríguez & Sadoski, 2002; van Hell & Mahn, 1997; Webb et al., 2020). Explicit mechanisms, such as explicit memory (also referred to as declarative memory), is a voluntary attention-based process that involves recall and recognition of facts/events and is mediated by medial-temporal lobe and prefrontal cortex structures (Ullman, 2004). Although it seems obvious that adults would rely on explicit mechanisms to learn some aspects of a new language (e.g., memorizing new vocabulary), what about learning the structure of language via statistical learning? Batterink and colleagues found that adults, with no intention to learn, mainly acquired explicit knowledge during SL tasks (Batterink et al., 2019; Batterink, Reber, & Paller, 2015; Batterink, Reber, Neville, et al., 2015; Batterink & Paller, 2017). However, more recent work has suggested that under the right circumstances, adults show evidence of implicit learning in naturalistic SL contexts (Alexander et al., 2022).

Additionally, most forms of SL measurements in adults tend to use explicit memory to measure SL. For instance, the forced choice task has participants actively try to recall which "word" is more familiar to them, which necessarily involves explicit memory processes (as the task requires one to explicitly reflect on their earlier experience with the statistical learning input). To get around this, some researchers have participants rate their forced-choice responses in terms of how confident they are. Smalle et al. (2022) theorized that when confident responses were above chance in a forced choice task, this was reflective of explicit memory. In contrast, if unconfident answers were above chance, this was reflective of implicit memory. The rationale for this operationalization is as follows: Confident answers are ostensibly related to explicit memory because participants possess meta-awareness of what they learned (reflecting explicit memory processes). In contrast, unconfident answers ostensibly reflect implicit memory because participants do not possess meta-awareness of what they learned (reflecting implicit memory processes).

The fact that SL is thought to be driven by implicit processes – yet adults appear to use a mixture of both implicit and explicit processing in SL tasks – suggests that manipulating the availability of explicit memory during learning might change the efficacy of SL. Explicit and implicit memory often compete with one another, and suppression of explicit memory can often improve forms of implicit memory (Ambrus et al., 2020; Borragán et al., 2016; Foerde et al., 2006; Frank et al., 2006; Galea et al., 2010; Nemeth et al., 2013; Virag et al., 2015). In other words, if adults use explicit processes, such as directed attention, to try to learn patterns within SL tasks, this may result in impaired implicit memory and consequently attenuated performance in SL tasks. However, these findings have been inconsistent, with Batterink and Paller (2019) reporting that adults' SL performance was not impaired if they were distracted by a given simultaneous attention/working memory task, suggesting that they were likely not using explicit mechanisms. Others (e.g., Ding et al. 2018) have suggested the opposite, that SL suffers if attentional resources are diverted. These inconsistencies could be caused by most SL measures testing explicit mechanisms. For example, the forced choice paradigm has participants actively try to recall which sounds are more familiar following exposure to a statistical stream, which necessarily invokes memory traces from that previously presented stream.

Both Batterink and Paller (2019) and Ding et al. (2018) manipulated explicit processing during the presentation of the statistical learning stream (i.e., by presenting attentional distractors alongside the to-be-learned sequence). However, another approach would be to manipulate the availability of explicit cognitive resources *prior* to the SL task and then assess whether participants who had fewer cognitive resources at learning would rely more on implicit learning mechanisms and thus show enhanced learning. This was the general approach taken by Smalle et al. (2022), who discovered that when explicit memory was suppressed, there was an increase in implicit memory and improved performance in a SL task. This was accomplished by using cognitive fatigue (CF) to temporarily inhibit explicit memory during an SL task. The present study similarly assigns participants to either a cognitively fatiguing condition or a control condition. Aligning with Smalle et al. (2022), the first hypothesis of the current study will be that participants that experience CF prior to a SL task will perform better in the SL task relative to participants who do not experience CF, presumably because the CF participants will use more implicit learning mechanisms, which are thought to better align with the optimal learning conditions of SL.

The present study additionally expands upon the approach taken by Smalle et al. (2022) by examining two additional participant factors thought to relate to the relative use of explicit learning and memory strategies. The first of these factors is age. Older adults frequently perform worse than younger adults in SL tasks (Schevenels et al., 2021). This performance decrease could be caused by aging effects, such as the fact that explicit memory processes tend to decline as a function of age. (Habib et al., 1996). Indeed, when Neger et al. (2014) conducted a visual SL study, they found that older adults performed worse in a SL task and suggested that this might be caused by age-related decline, such as slower processing speed. Furthermore, Herff et al. (2020) found no significant difference in SL scores overall between younger and older participants, but they did discover that higher cognitive assessment scores predicted steeper learning trajectories in both older and younger adults. Older adults with high cognitive assessment scores had similar SL performances to younger high cognitive assessment adults. However, older adults with low cognitive assessment scores had lower SL performance compared to younger adults with matched scores. Thus, it was proposed that the older low cognitive assessment adults' SL performance was due to age-related cognitive decline, and performance in low cognitive assessment younger adults was not likely due to functional impairment. Therefore, it can be reasoned that age-related decline has a negative effect on SL performance. In addition, the reason it is most likely explicit memory causing decline in SL and not implicit is because implicit memory does not appear to be as affected by aging (Jelicic, 1995). However, newer research has suggested that implicit memory could also be negatively affected by age (Ward et al., 2013).

Therefore, the present study will examine how SL performance differs in older and younger adults when placed in a cognitively fatiguing condition or a control condition. Due to aging affecting explicit memory, the study predicts there will be a main effect between older and younger participants, with younger participants outperforming the older participants. It is also believed that cognitive fatigue will encourage participants to switch to using more implicit mechanisms to reduce cognitive load, and since older participants' implicit memory may be less affected by aging (although see Ward et al., 2013), they might show more comparable performance to younger adults under conditions of CF. Thus, the paper's second hypothesis is that there will be an interaction effect between condition (CF, control) and age group (younger, older), with younger and older participants in the CF condition performing more comparably than younger and older participants in the control condition (in which younger participants are expected to outperform older participants).

Given the reported association between CF and SL (Smalle et al., 2022), it is also important to identify individual factors that might make one more or less likely to be susceptible to the effects of cognitive fatigue. One promising construct that has been recently identified (Peng et al., 2022) is the personality trait Need for Cognition (NFC). NFC measures how much a person tends to engage in and enjoy thinking (Cacioppo & Petty, 1982). For instance, participants low in NFC preferred simple instructions, rather than complex instructions and the opposite was found in high NFC participants, who preferred complex instructions instead of simple ones. Specifically, in the context of understanding the association between NFC and cognitive fatigue, Peng et al. (2022) found that nurses who scored high in the personality trait Need for Cognition (NFC) were less affected by CF than those who scored low in NFC. Peng et al. (2022) theorized that this difference could be explained by the dual-process model of decision-making. The dual-process model states that there are two processing systems individuals use: a heuristic system and an analytic system (Evans, 2012). The heuristic system is greatly affected by emotion, is intuitive, automated, involves rapid parallel processing, and consumes fewer resources than the analytic system. Conversely, the analytic system is slow and based on cognitively effortful processing. Evans (2012) also reasoned that these processes compete for the dominant role of decision-making. Therefore, Peng et al. (2022) believe that when nurses were under cognitive resource deficit, caused by CF, low NFC decision-makers fell back on the cognitively easier route, the heuristic system, as it required fewer cognitive resources. However, individuals who were high in NFC used the analytic system as they tended to use that system more and usually devote more cognitive resources to thinking. These factors helped buffer against the effects of cognitive fatigue. Moreover, Ackerman and Kanfer (2009) claimed that the personality trait Desire to Learn/Typical Intellectual Engagement (TIE) also had a mitigating effect on subjective CF. TIE and NFC have a high correlation with each other, and both are measurements of a person's engagement in intellectual (or cognitive) activities (Woo et al. 2007). Therefore, it is expected that high NFC participants will not be as affected by CF and thus will not shift to the using the implicit memory system, whereas low NFC participants in the CF condition will. Thus, the third hypothesis of the present study is that NFC (low, high) will interact with condition (CF, control), with low NFC participants in the CF condition performing better on SL tasks compared to both low NFC participants in the control condition and all high NFC participants, regardless of condition.

The current study was entirely online and recruited participants into one of two conditions, the cognitive fatigue condition (CF) and control condition, and from one of two age ranges: younger adults (18-30 years old), and older adults (55 years old or older). Participants started the study by completing a self-report fatigue scale before and after finishing a cognitively fatiguing task conceptually similar to the one used by Smalle et al. (2022). Participants then listened to streams of spoken syllables, which adhered to the statistical regularities outlined in Saffran et al. (1996), and completed a "syllable detection" task during the streams as an implicit measure of SL. The syllable detection task is thought to be a more implicit measurement of SL (Batterink et al., 2015; Kim et al., 2009; Turk-Browne et al., 2005). A forced-choice recognition task was then completed to measure overall SL and measure explicit and implicit learning.

Participants then filled out the Need for Cognition scale (NFC; Cacioppo et al., 2013), and a simple demographics questionnaire. As noted previously, a main effect of CF was predicted, with participants in the CF (versus the control) condition performing better on the implicit SL measures. Additionally, condition was expected to interact with both age and NFC, given the prior research assessing how both age and NFC influence the tendency to engage in explicit processing.

Method

Participants

A total of 200 participants were recruited for the study, and 168 participants were included in the analyses. 32 of the participants were excluded for two reasons: (1) low performance (<75% accuracy) on the cognitive processing task used to manipulate CF, and (2) combined low performance on both the syllable detection (<1 d-prime) and forced-choice (<50% accuracy) judgment. For example, participants were excluded if they did not respond at any point during the syllable detection task or if they were responding to all syllables presented during the task, and they performed worse than chance at the forced-choice task. The first criterion was meant to exclude participants who did not consistently engage with the cognitive fatigue task, thus representing noncompliance with the experimental manipulation. The second criterion was implemented because poor performance on *both* statistical learning measures reflects either a misunderstanding of the task or noncompliance in listening to the statistical learning streams.

All participants were recruited from Amazon Mechanical Turk, a large-scale online participant pool, via CloudResearch (Litman et al., 2017), which interfaces with Mechanical Turk and allows for a wider range of recruitment parameters. In the present study, the younger participants were recruited within an age parameter of 18-30 years old, and the older participants were recruited within an age parameter of 55 years old or older. All participants had to have a minimum 90% approval rating from prior Mechanical Turk assignments and had to have passed internal attention checks administered by CloudResearch. A description of participant characteristics, divided by condition and age group, is provided in Table 1. All participants (regardless of data exclusion) were paid $7.50 USD for completing the study.

Materials and Procedure

The study was conducted online with participants being informed beforehand that in order to complete the study they needed a computer with a keyboard and some way to listen to the computer's audio, with headphones being the preferred method. Participants were recruited into two conditions: the Cognitive Fatigue (CF) condition, or the control condition. Both conditions were run within one week of each other on Mechanical Turk (CF condition first, followed by the control condition). Participants who completed the CF condition were ineligible to enroll in the control condition. This method of condition assignment was selected, as opposed to randomizing condition upon loading the experiment, to ensure even sample sizes across conditions. Participants in both conditions completed the same tasks, with only the time constraints of the cognitive processing task being different (similar to Smalle et al., 2022).

Table 1

Descriptive statistics comparing the two recruitment factors (condition: CF, control and age: younger, older)

	CF (*n* = 86)		Control (*n* = 82)	
	Younger (*n* = 49)	Older (*n* = 37)	Younger (*n* = 46)	Older (*n* = 36)
Self-Reported Headphone Use	.78 (.42)	.86 (.35)	.85 (.36)	.61 (.49)
Headphone Screening Pass	.51 (.50)	.62 (.49)	.54 (.50)	.47 (.51)
Gender (woman)	.37 (.49)	.57 (.50)	.41 (.50)	.67 (.48)
Education	3.96 (1.17)	4.35 (1.32)	4.00 (1.38)	4.00 (1.29)
Bilingual	.22 (.42)	.08 (.28)	.33 (.47)	.08 (.28)
Musical Training	.33 (.47)	.32 (.48)	.39 (.49)	.42 (.50)
Need for Cognition	59.45 (14.70)	61.86 (17.28)	58.17 (13.91)	62.75 (18.40)

Note: CF = cognitive fatigue condition. Self-Reported Headphone Use, Headphone Screening Pass, Gender (woman), Bilingual, and Musical Training are represented as proportions (yes = 1; no = 0). Standard deviations are represented in parentheses.

Participants first completed a short auditory assessment to check their auditory setup. The auditory assessment consisted of three components. First, participants completed a volume adjustment, in which a musical excerpt was played (amplitude normalized to the same level as the rest of the auditory stimuli in the experiment) and participants adjusted their computer volume such that the excerpt was being played at a comfortable volume. Second, participants answered a question about whether they were wearing headphones or earbuds (yes or no). Third, participants completed a short performance-based headphone assessment, adapted from Milne et al. (2021). Following this auditory assessment, participants completed a simple cognitive fatigue self-report question (conceptually similar to Smalle et al., 2022) to assess fatigue, with response options ranging from 1 (*Very slightly or not at all*) to 5 (*Extremely*). This single question about cognitive fatigue was administered before and after completing a cognitive processing task, in which the presentation speed of the to-be-judged items has been associated with changes in cognitive fatigue (Borragán, et al., 2017).

For the cognitive processing task, participants were alternately shown digits (1 to 4 and 6 to 9) or letters (A,C,T,L,N,E,U, and P), during which they had to press spacebar if the current letter was a repeat of the last letter shown, or they had to press 1 if the number shown was odd, or 2 if it was even. Participants in the CF condition had a dynamic presentation rate of the stimuli, where the time allotted for participants to respond was based on how well they were doing at the time. For instance, the response window (time available to make a response) started at 3000 milliseconds (ms) - the same presentation rate as the control condition - and was shortened by 100 ms every time a participant made five correct judgments in a row. In contrast, the window was lengthened by 100 ms every time a participant made an incorrect judgment (up to 3000 ms). This adaptive procedure was calibrated so that each individual participant was to maintain ~83.3% accuracy (i.e., maintaining a presentation rate in which participants would be able to correctly respond to approximately 5 of every 6 items). In contrast, participants in the control condition had a fixed response window of 3000 ms, which allowed participants to respond at their leisure and did not engender time constraints thought to underlie cognitive fatigue (e.g., Smalle et al., 2022). All participants were given practice trials to become familiar with the cognitive fatigue task (first practicing the number judgments, followed by practicing the letter judgments, followed by practicing the interleaved number and letter judgments similar to the main task). The cognitive fatigue task lasted 16 minutes for each participant, and participants were given 10-second breaks every three minutes.

Participants then listened to streams of spoken syllables, which adhered to the statistical regularities outlined in Saffran et al. (1996) apart from the syllable set, which was taken from Choi et al. (2020). There were twelve syllables in total (*pau*, *to*, *ne*, *mai*, *pu*, *ki*, *nu*, *ra*, *fi*, *ga*, *mi*, *lu*), which were configured to create four tri-syllabic "words" (e.g., *pau-to-ne*, *mai-pu-ki*, *nu-ra-fi*, *ga-mi-lu*). This configuration means that the syllables had different transitional probabilities, depending on whether they occurred within (versus between) a word. Continuing the example from the previous sentence, if a participant heard *pau*, there would be a 100% probability of hearing *to* as the next syllable. In contrast, if a participant heard *ne* there would be a 33.3% probability of hearing either *mai*, *nu*, or *ga* (as *ne* is the final syllable of the "word" and could thus be followed by any of the other three "words" in the set). Syllable orderings within "words" were counterbalanced across participants to eliminate the possibility that learning was driven by specific syllable combinations, as each syllable appeared in the first, second, and third position across participants.

During exposure to the statistical stream, participants also completed a simple "syllable detection" task. The "syllable detection" task was used as a measure of implicit learning, as participants should become faster at responding to syllables in the middle and final positions of "words" as they learn about the statistical structure (e.g., see Batterink & Paller, 2017). In the “syllable detection” task, participants saw a syllable printed on the screen (e.g., “ki”) and had to press the space bar as quickly and accurately as possible whenever they heard the syllable.

Participants then completed a forced-choice recognition task to examine their implicit and explicit memory of the hidden words from the statistical language. For the task, participants had to listen to one of the “words” from the exposure sounds and a new non-word. They were then asked to choose which sound they found more familiar based on the sounds heard in the syllable detection task. The non-word was formed from three of the 12 syllables, and the three syllables of the non-words never followed each in the word stream, so they were completely novel to the participant. After participants chose which word sounded more familiar, they were then asked to rate how confident they were in their decision (e.g., “I guessed”, “it sounds familiar, but I have no clear memory”, and “I recalled from exposure”). Answers with “I recalled from exposure” were coded as confident, and treated as explicit recall, whereas answers with “I guessed” or “it sounds familiar, but I have no clear memory” were coded as unconfident responses and measured as implicit recognition. This approach to differentiating implicit and explicit memory was in direct accordance with Smalle et al. (2022).

Following the forced-choice recognition task, participants were then asked to fill out the Need for Cognition scale (NFC; Cacioppo et al., 2013), and a demographics questionnaire. The NFC scale was an 18-item scale that consisted of statements which participants had to rate from 1 to 5, with 1 being extremely uncharacteristic of themselves and 5 being extremely characteristic of themselves. For example, one statement used was “I prefer complex to simple problems.” Additionally, the demographics questionnaire asked participants about their gender, age, how many languages they speak, and about their musical history. Apart from age, the demographics questionnaire was meant to assess how equated the participant groups were and thus these factors were not formally included in the analyses.

The stimulus materials and data files, including scripts for analysis, are available on an open science repository: https://osf.io/sxrfj/

Results

Fatigue Self-Report

A 2 x 2 one-between-one-within ANOVA on the Fatigue Self-Report scores was conducted with condition (CF, control) as the between-participant factor and time (before and after the cognitive processing task) as the within-participant factor. The results showed no significant main effect for condition, $F(1,166) = .00$, p = .99, partial $\eta^2 = .00$, and a significant main effect for time, *Greenhouse-Geisser* adjusted $F(1,166.00) = 182.23$, p < .001, partial $\eta^2 = .52$. For time, participants rated their fatigue significantly higher after completing the cognitive processing task ($M = 3.30$, $SD = 1.18$) compared to before they started ($M = 2.00$, $SD = 1.20$). There was also a significant condition-by-time interaction, *Greenhouse-Geisser* adjusted $F(1,166.00) = 4.91$, $p = .03$, partial $\eta^2 = .03$, with participants in the CF condition reporting significantly higher fatigue after the fatigue task than participants in the control condition.

Cognitive Processing Task

Participants in the CF condition experienced a significantly faster mean presentation rate for items in the cognitive processing task ($M = 1510$ ms, $SD = 447$ ms) compared to participants in the control condition, whose presentation rate was fixed at 3000 ms. A one-sample *t*-test against a known mean of 3000 ms confirmed that the presentation rate in the CF condition was significantly faster than the presentation rate in the control condition, $t(85) = 30.89$, $p < .001$, $d =$

3.33. Participants in the CF condition also had significantly lower mean accuracy (*M* = 87.3%, *SD* = 3.6%) compared to participants in the control condition (*M* = 93.4%, *SD* = 8.2%), *Welch* *t*(110.26) = 6.11, *p* < .001, d = 0.95 in the cognitive processing task.

Syllable Detection Task

Participant accuracy in the syllable detection task was operationalized in terms of signal detection theory. Participant sensitivity to detecting target syllables, measured through d-prime (*d'*), was used to indicate whether participants could differentiate target syllables from non-target syllables (with a value significantly above zero indicating an ability to differentiate targets from non-targets). As such, to assess whether participants were sensitive to detecting target syllables in the syllable detection task, a one-sample *t*-test against a known mean of zero was used. Overall, participants' d-prime values (*M* = 2.12, *SD* = 0.92) were significantly above zero, *t*(167) = 29.91, *p* < .001, d = 2.92, indicating that participants engaged with the syllable detection task and reliably differentiated target from non-target syllables.

To assess evidence of SL within the syllable detection task, a composite value was calculated from participants' response times to syllables within the initial and final position of the "words" of the statistical stream. Participants' response times to final position syllables were subtracted from their response times to initial position syllables and then divided by their mean response time, resulting in a value that represented the relative *facilitation* of responding to final position syllables, normalized by overall response time. A value greater than zero represents facilitation in line with SL, and thus performance was first assessed via a one-sample *t*-test against a known mean of zero. Overall, the composite value (*M* = .024, *SD* = .098) was significantly above zero, *t*(165) = 3.20, *p* = .002, d = 0.25, indicating that SL occurred and was measurable within the syllable detection task, which served as both SL exposure and an implicit measure of learning (although the effect size was small). Observing significant SL within the syllable detection task was a necessary precondition for examining the effects of condition, age, and NFC on learning; thus, the next two sections detail the results from these analyses.

2 x 2 x 2 ANOVA Syllable Detection Task

A 2 x 2 x 2 ANOVA was conducted with the SL composite measure from the syllable detection task as the dependent variable and condition (CF, control), age (young, old), and NFC score (high, low, with high being above the median score of 62.5 and low being below the median score of 62.5) as the independent variables. The results indicated there was no significant main effect for condition, $F(1, 165) = .19$, $p = .67$, partial $\eta^2 = .001$, no significant main effect for age, $F(1, 165) = .18$, $p = .67$, partial $\eta^2 = .001$, and no significant main effect for NFC, $F(1, 165) = 1.52$, $p = .22$, partial $\eta^2 = .01$. There was also no significant interaction effect between condition and age, $F(1, 165) = .38$, $p = .54$, partial $\eta^2 = .002$, no significant interaction effect between condition and NFC, $F(1, 165) = .052$, $p = .82$, partial $\eta^2 = .000$, no significant interaction effect between age and NFC, $F(1, 165) = 1.73$, $p = .19$, partial $\eta^2 = .011$, and no significant interaction effect between condition, age, and NFC, $F(1, 165) = 3.04$, $p = .083$, partial $\eta^2 = .019$.

Forced Choice Task Accuracy

Participants overall ($M = .63$, $SD = .16$) and in both conditions (fatigue: $M = .64$, $SD = .15$; control: $M = .62$, $SD = .16$), performed above chance (0.5) for the forced choice task, assessed through a one-sample *t*-test against a known mean of 0.5 (overall: $t(167) = 10.73$, $p < .001$, $d = 0.83$; fatigue: $t(85) = 8.67$, $p < .001$, $d = 0.94$; control: $t(81) = 6.56$, $p < .001$, $d = 0.72$), corroborating the findings of the syllable detection task that SL occurred (albeit with larger effect sizes than those observed in the syllable detection task). Confident answers, which were considered in terms of explicit memory (all: 45%; fatigue: 44%; control: 37%), were also above chance in overall and in both conditions, overall: (*M* = .71, *SD* = .23) *t*(150) = 11.40, $p < .001$, *d* = 0.93; fatigue: (*M* = .74, *SD* = .22) *t*(76) = 9.82, $p < .001$, *d* = 1.12; control: (*M* = .68, *SD* = .24) *t*(73) = 6.52, $p < .001$, *d* = 0.76. Unconfident answers, which were considered in terms of implicit memory (all: 55%; fatigue: 56%; control: 63%), were above chance in overall and in both conditions, overall: (*M* = .57, *SD* = .21) *t*(158) = 4.44, $p < .001$, *d* = 0.35; fatigue: (*M* = .58, SD = .20) *t*(80) = 3.52, $p < .001$, *d* = 0.39; control: (*M* = .57, *SD* = .23) *t*(77) = 2.81, *p* = .006, *d* = 0.32. Some participants answered all questions either confidently or unconfidently, therefore there was no data for those participants for their confident or unconfident responses.

2 x 2 x 2 ANOVA Overall Forced Choice Task

A 2 x 2 x 2 ANOVA was conducted with proportion of correct choices in the forced-choice recognition task as the dependent variable and condition (CF, control), age (young, old), and NFC score (high, low) as the independent variables. There was no significant main effect of condition, *F*(1, 167) = .60, *p* = .44, partial η^2 = .004, but the results did indicate there was a significant main effect of age, *F*(1, 167) = 4.02 , *p* = .047, partial η^2 = .025, with younger participants (*M* = .65, SD = .16) choosing more correct choices than older participants (*M* = .61, SD = .14), and a significant main effect of NFC, *F*(1, 167) = 5.96 , *p* = .016, partial η^2 = .036, with participants high in NFC (*M* = .66, SD = .16) having significantly more correct choices than those low in NFC (*M* = .60, SD = .15). There was also no significant interaction effect between any of the independent variables; condition and age, *F*(1, 167) = .17, *p* = .68, partial η^2 = .001;

condition and NFC, $F(1, 167) = .92$, $p = .34$, partial $\eta^2 = .006$; age and NFC, $F(1, 167) = .16$, $p = .69$, partial $\eta^2 = .001$; condition, age, and NFC, $F(1, 167) = .22$, $p = .64$, partial $\eta^2 = .001$.

2 x 2 x 2 ANOVA Confident Responses in Forced Choice Task

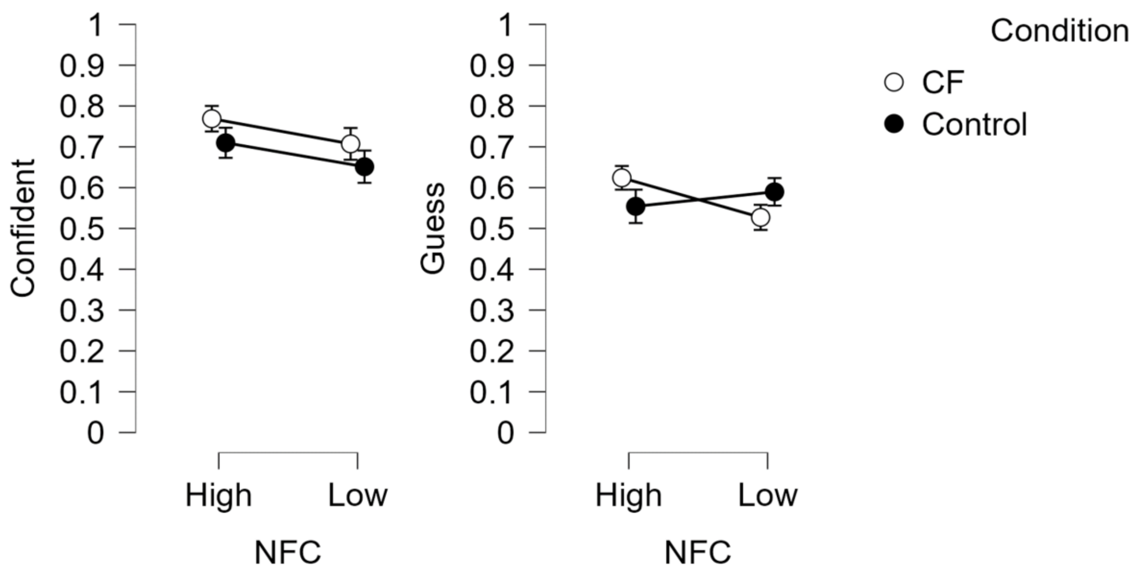
A 2 x 2 x 2 ANOVA was conducted with proportion of correct confident choices in the forced-choice recognition task as the dependent variable and condition (CF, control) age (young, old), and NFC score (high, low) as the independent variables. The results indicated there was no significant main effect of condition, $F(1, 150) = 2.71$, $p = .10$, partial $\eta^2 = .019$, no significant main effect of age, $F(1, 150) = .42$, $p = .52$, partial $\eta^2 = .003$, no significant main effect of NFC, $F(1, 150) = 2.02$, $p = .16$, partial $\eta^2 = .014$, and no significant interaction effect between any of the independent variables; condition and age, $F(1, 150) = .25$, $p = .62$, partial $\eta^2 = .002$; condition and NFC, $F(1, 150) = .042$, $p = .84$, partial $\eta^2 = .000$; age and NFC, $F(1, 150) = 1.90$, $p = .17$, partial $\eta^2 = .013$; condition, age, and NFC, $F(1, 150) = 2.98$, $p = .086$, partial $\eta^2 = .020$.

2 x 2 x 2 ANOVA Unconfident Responses in Forced Choice Task

A 2 x 2 x 2 ANOVA was conducted with proportion of correct unconfident choices in the forced-choice recognition task as the dependent variable and condition (CF, control) age (young, old), and NFC score (high, low) as the independent variables. The results indicated there was no significant main effect of condition, $F(1, 158) = .001$, $p = .97$, partial $\eta^2 = .000$, no significant main effect of age, $F(1, 158) = .014$, $p = .90$, partial $\eta^2 = .000$, no significant main effect of NFC, $F(1, 158) = .59$, $p = .44$, partial $\eta^2 = .004$. There was no significant interaction effect between any of the variables; condition and age, $F(1, 158) = .82$, $p = .37$, partial $\eta^2 = .005$; age and NFC, $F(1, 158) = .062$, $p = .80$, partial $\eta^2 = .000$; condition, age, and NFC, $F(1, 158) = .12$, $p = .73$, partial $\eta^2 = .001$. There was however a borderline significant interaction effect between condition and NFC, $F(1, 158) = 3.72$, $p = .056$, partial $\eta^2 = .024$. Participants who scored low in NFC had worse performance in the fatigue condition ($M = .53$, $SD = .19$) compared to low NFC participants in the control condition ($M = .59$, $SD = .22$) and, in contrast, participants who scored high in NFC showed the opposite results where they performed better in the fatigue condition ($M = .62$, $SD = .19$) than those in the control condition ($M = .55$, $SD = .25$; see Figure 1for more details). This suggests that fatigue increases performance of implicit SL for high NFC participants and reduced implicit SL for low NFC participants.

Figure 1

Visualization of how Condition and Need for Cognition (NFC) influenced AFC accuracy for both confident (left) and unconfident/guess (right) trials.



Note: NFC used a median split. The y-axis represents proportion correct, with chance performance being 0.5. Error bars represent plus or minus one standard error of the mean. The confident responses are plotted for comparison (no significant main effects or interactions were observed).

Discussion

There were three main aims of the current study. The first aim was to assess whether the main findings of Smalle et al. (2022) could be replicated, where it was found that cognitive fatigue increased SL (specifically through increasing implicit measures of SL and decreasing explicit measures of SL). The second aim was to explore how age influenced SL and how age might interact with CF. The association between age and SL has been mixed in the literature, with some studies finding that younger participants outperform older in SL tasks (Neger et al, 2014; Schevenels et al., 2021), whereas other have found generally comparable SL across younger and older adults (Herff et al., 2020). Regardless of the main effect of age on SL, the way in which age might interact with CF is understudied but theoretically motivated, given the described changes in explicit and implicit processing as a function of aging. The final aim of the study, which has not been addressed in previous research, was to discover if NFC affected SL performance, and if NFC would mediate CF akin to the findings of Peng et al. (2022).

A necessary precondition of being able to assess evidence in support of these aims is to observe that SL occurred. This was observed robustly across multiple measures, both implicit and explicit, in the current study. Participants performed significantly above chance in both the syllable detection task and the "confident" and "unconfident" forced-choice task. However, regarding the first aim of the study, there was no significant main effect in any of the SL assessments between the control and CF condition, representing a failure to replicate Small et al. (2022). (The one observed difference between conditions was high NFC individuals scoring better when fatigued compared to low NFC individuals and is discussed more in depth later).

There are two possible reasons the current study could not replicate the findings of Smalle et al. (2022), both relating to the relative amount of cognitive fatigue that was engendered by the CF and control conditions. If insufficient fatigue was engendered by the CF manipulation, participants may have not switched their statistical learning style, and indeed the current study did not find evidence of decreased explicit SL and increased implicit SL between conditions. However, this is not the most probable explanation, as participants reported a significant difference in fatigue before and after the cognitive load task and between conditions after completing the cognitive load task (represented as a significant time-by-condition interaction of fatigue scores). Thus, the more likely explanation is that there was too much fatigue in the control condition, or more specifically, not enough of a difference in CF between conditions. This is supported by the fact that participants in the control condition reported significantly more fatigue after undergoing the cognitive load task. This was also found in the Smalle et al. (2022) study between high and low CF conditions. It was found that there was no significant difference between low and high CF conditions in all three sections of the forced choice task: overall, confident responses, and unconfident responses. In fact, there was only a significant difference between the high CF condition and the control group in unconfident responses and both high and low CF groups compared to the control group in overall responses.

Regarding the second aim of the current study, there was evidence that younger participants outperformed older participants, contradicting prior research that found no significant difference between ages (Herff et al., 2020). Instead, the results were similar to Neger et al. (2014) and Schevenels et al. (2021), where there was significant difference between age groups, or when older participants had low cognitive assessment scores (Herff et al., 2020) which will be further discussed when describing the limitations of the current study. The current study also found that there was no significant difference in any other SL measures and no significant interaction between age and conditions in any of the SL measures. This suggests that there might have been aging effects in SL performance.

Regarding the third aim of the current study, there was some evidence that NFC affected SL performance, and that high NFC mediated CF akin to the findings of Peng et al. (2022). It was found there was a significant difference between high and low NFC in overall responses in the forced choice task, indicating that participants high in NFC perform better in SL tasks than those with low NFC. Since forced choice tasks may measure the more explicit aspect of SL, it can be argued that participants high in NFC have better explicit SL than participants low in NFC. However, as there was no significant difference when independently considering confident responses, it is more appropriate to conclude that NFC is associated with a more general increase in SL.

There was also a significant interaction effect in unconfident responses in the forced choice task with participants high in NFC in the fatigue condition outperforming participants high in NFC in the control condition, while the opposite was found in low NFC participants, where low NFC participants in the fatigue condition performed worse than low NFC participants in the control condition. This indicates that fatigue increases implicit SL in high NFC individuals and decreases it for those who are low in NFC. This is similar to the Peng et al. (2022) study where high NFC meditated the effects of being fatigued and those low in NFC performed worse at tasks that required cognition, such as tasks that require critical thinking. However, there could be an unknown factor that caused the interaction. For instance, high NFC participants may have higher standards for what they deem as confident responses, so answers that would be rated as confident in low NFC participants is instead rated as unconfident. There was also no significant interaction in the syllable detection task, which is thought to be a more implicit measurement, which also supports the theory that another factor is at cause.

Limitations and Future Directions

One limitation of the current study is that selection bias may have occurred. For instance, it is possible that the current study did not find as much SL difference between ages as it could have because older participants with aging effects may have been filtered out through the data exclusion parameters used in the current study. Relatedly, the sample of older adults on Mechanical Turk is not likely to be representative in terms of cognitive ability and decline. Most older adults who experience cognitive and perceptual processing deficits from aging effects are not going to create an account and participate in an online study on CloudResearch and Mechanical Turk, and the ones that do might not have fully understood and completed the syllable detection task or the cognitive load task, which would have caused their data to be discarded from the main analyses. A simple, if more expensive, solution is to have the study take to place in person. While this may not guarantee aging effects in older participants, it does decrease the number of barriers for potential participants with aging affects. In-person studies also opens the possibility for more objective measures of fatigue, because another limitation is that the study used a self-report scale to measure fatigue. Thus, there is a legitimate concern that actual fatigue did not occur. Therefore, future studies should add physiological measures of fatigue, such as pupil dilation (Bafna et al., 2021) and heart rate variability (Tran et al., 2009).

Another potential limitation is that the current study used a syllable detection task as another measure of SL, which deviated from the design of Smalle et al. (2022). The potential problem with this additional task is that it may have made the participants more aware of the syllable stream than they normally would have. For instance, to complete this task participants were required to actively pay attention to the sounds used during the stream, and thus were more of the syllables being used. This may have triggered more explicit mechanisms to occur, such as trying to actively remember which syllables occurred right before the target syllable. Future studies should include another set of conditions where one group completes a syllable detection task and a control group that does not.

As discussed earlier, another possible limitation is that there was not enough of a CF difference between conditions. A simple solution is that future studies use a control condition that is deliberate more differentiated from the CF condition, wherein participants do not undergo any form of task that could increase fatigue. Future studies could also instead add a third condition with a relaxing condition instead of CF. For instance, participants could listen to relaxing music or nature sounds. Schertz and Berman (2019) reported that nature sounds increased working memory and other cognitive processes. Therefore, a relaxing condition could create greater contrast for the fatigue condition, as relaxing could create the opposite effects of fatigue, such as an increase in explicit SL which may cause implicit SL to decrease. This would provide a stronger test of the findings of Smalle et al. (2022); if CF and a relaxation condition result in comparable SL, despite having opposite effects on available cognitive processing, this would challenge the notion that available cognitive resources in the moment are significantly driving SL performance differences.

Future studies should further examine the effects of NFC and personality on SL, particularly given the intriguing (yet borderline) significant interaction between NFC and SL observed in the present study. This is an important area to research as there is little data available on how NFC or other personality factors affect SL. A future study could investigate if other personality dimensions also affect SL. For instance, the personality trait Desire to Learn/Typical Intellectual Engagement (TIE) which had a mitigating effect on CF similar to NFC and was highly correlated with NFC (Woo et al. 2007), could be used and could conceptually replicate the present findings. Additionally, while the syllable detection task did not find any significant difference between high and low NFC in SL performance, other types of SL measures might. A future study could examine how NFC affects visual SL instead of auditory SL. While it may seem evident that all forms of SL would react similarly to the same factors, there is evidence that auditory and visual SL are affected differently. For instance, Siegelman et al. (2018) found that auditory SL was affected by entrenchment factors of their native language, but there was no such entrenchment in visual SL. Thus, examining how the measured factors (CF, age, and NFC) generalize to non-linguistic and non-auditory forms of SL would provide a better sense of the generalizability of the findings.

Conclusion

The current study built upon existing research to improve the existing understanding of what factors affect SL. The present findings indicate that a significant difference in reported fatigue is not sufficient to affect SL outcomes. It is suggested that future studies, which examine the effects of CF on SL, include a condition that does not significantly increase reported fatigue after CF tasks. The study also supports past research that suggests that age does affect SL performance, and it is recommended that future studies involving older participants not be solely online and include an option for participants to take part in the study in person. Finally, the study found that NFC does affect SL performance, with high NFC participants performing better in certain SL tasks and CF could increase implicit SL in high NFC individuals and decrease implicit SL in low NFC individuals. Given the importance of SL mechanisms in language acquisition and pattern extraction throughout the lifespan, understanding the individual factors that can help or hinder SL is a necessary topic for future investigations.

References

Ackerman, P. L., & Kanfer, R. (2009). Test length and cognitive fatigue: An empirical examination of effects on performance and test-taker reactions. *Journal of Experimental Psychology: Applied*, *15*(2), 163–181. https://doi.org/10.1037/a0015719

Alexander, E., Van Hedger, S. C., & Batterink, L. J. (2022). Learning words without trying: Daily second language podcasts support word-form learning in adults. *Psychonomic Bulletin & Review*, Advance online publication. https://doi.org/10.3758/s13423-022-02190-1

Ambrus, G. G., Vékony, T., Janacsek, K., Trimborn, A. B. C., Kovács, G., & Nemeth, D. (2020). When less is more: Enhanced statistical learning of non-adjacent dependencies after disruption of bilateral DLPFC. *Journal of Memory and Language*, *114*, 104144. https://doi.org/10.1016/j.jml.2020.104144

Batterink, L. J., & Paller, K. A. (2017). Online neural monitoring of statistical learning. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, *90*, 31–45. https://doi.org/10.1016/j.cortex.2017.02.004

Batterink, L. J., & Paller, K. A. (2019). Statistical learning of speech regularities can occur outside the focus of attention. *Cortex*, *115*, 56–71. https://doi.org/10.1016/j.cortex.2019.01.013

Batterink, L. J., Paller, K. A., & Reber, P. J. (2019). Understanding the Neural Bases of Implicit and Statistical Learning. *Topics in Cognitive Science*, tops.12420. https://doi.org/10.1111/tops.12420

Batterink, L. J., Reber, P. J., Neville, H. J., & Paller, K. A. (2015). Implicit and explicit contributions to statistical learning. *Journal of Memory and Language*, 62–78. https://doi.org/10.1016/j.jml.2015.04.004

Batterink, L. J., Reber, P. J., & Paller, K. A. (2015). Functional differences between statistical learning with and without explicit training. *Learning & Memory*, *22*(11), 544–556. https://doi.org/10.1101/lm.037986.114

Bafna, T., & Hansen, J. P. (2021). Mental fatigue measurement using eye metrics: A systematic literature review. *Psychophysiology, 58*(6). https://doi.org/10.1111/psyp.13828

Borragán, G., Slama, H., Bartolomei, M., & Peigneux, P. (2017). Cognitive fatigue: A Time-based Resource-sharing account. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, *89*, 71–84. https://doi.org/10.1016/j.cortex.2017.01.023

Borragán, G., Slama, H., Destrebecqz, A., & Peigneux, P. (2016). Cognitive Fatigue Facilitates Procedural Sequence Learning. *Frontiers in Human Neuroscience*, *10*, 86. https://doi.org/10.3389/fnhum.2016.00086

Cacioppo, J. T., & Petty, R. E. (1982). The need for cognition. *Journal of Personality and Social Psychology*, *42*, 116–131. https://doi.org/10.1037/0022-3514.42.1.116

Cacioppo, J. T., Petty, R. E., & Kao, C. F. (2013). Need for Cognition Scale. Measurement Instrument Database for the Social Science. Retrieved from www.midss.ie

de Vries, M. H., Barth, A. C. R., Maiworm, S., Knecht, S., Zwitserlood, P., & Flöel, A. (2010). Electrical stimulation of Broca's area enhances implicit learning of an artificial grammar. *Journal of Cognitive Neuroscience*, *22*(11), 2427–2436. https://doi.org/10.1162/jocn.2009.21385

Ding, N., Pan, X., Luo, C., Su, N., Zhang, W., & Zhang, J. (2018). Attention is required for knowledge-based sequential grouping: Insights from the integration of syllables into words. *The Journal of Neuroscience, 38*(5), 1178–1188. https://doi.org/10.1523/JNEUROSCI.2606-17.2017

Evans, J. St. B. T. (2012). Dual-process theories of deductive reasoning: Facts and fallacies. In *The Oxford handbook of thinking and reasoning* (pp. 115–133). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199734689.013.0008

Foerde, K., Knowlton, B. J., & Poldrack, R. A. (2006). Modulation of competing memory systems by distraction. *Proceedings of the National Academy of Sciences of the United States of America*, *103*(31), 11778–11783. https://doi.org/10.1073/pnas.0602659103

Frank, M. J., O'Reilly, R. C., & Curran, T. (2006). When memory fails, intuition reigns: Midazolam enhances implicit inference in humans. *Psychological Science*, *17*(8), 700–707. https://doi.org/10.1111/j.1467-9280.2006.01769.x

Galea, J. M., Albert, N. B., Ditye, T., & Miall, R. C. (2010). Disruption of the dorsolateral prefrontal cortex facilitates the consolidation of procedural skills. *Journal of Cognitive Neuroscience*, *22*(6), 1158–1164. https://doi.org/10.1162/jocn.2009.21259

Gu, Y., & Johnson, R. K. (1996). Vocabulary learning strategies and language learning outcomes. *Language Learning*, *46*, 643–679. https://doi.org/10.1111/j.1467-1770.1996.tb01355.x

Habib, R., Jelicic, M., & Craik, F. I. M. (1996). Are implicit memory deficits in the elderly due to differences in explicit memory processes? *Aging, Neuropsychology, and Cognition*, *3*(4), 264–271. https://doi.org/10.1080/13825589608256629

Herff, S. A., Zhen, S., Yu, R., & Agres, K. R. (2020). Age-dependent statistical learning trajectories reveal differences in information weighting. *Psychology and Aging*, *35*(8), 1090–1104. https://doi.org/10.1037/pag0000567

Jelicic, M. (1995). Aging and Performance on Implicit Memory Tasks: A Brief Review. *International Journal of Neuroscience*, *82*(3–4), 155–161. https://doi.org/10.3109/00207459508999798

Kennedy, D., & Norman, C. (2005). What don't we know? *Science (New York, N.Y.)*, *309*(5731), 75. https://doi.org/10.1126/science.309.5731.75

Kim, R., Seitz, A., Feenstra, H., & Shams, L. (2009). Testing assumptions of statistical learning: Is it long-term and implicit? *Neuroscience Letters*, *461*(2), 145–149. https://doi.org/10.1016/j.neulet.2009.06.030

Litman, L., Robinson, J. & Abberbock, T. Behavioral Research Methods, (2017) 49: 433. https://doi.org/10.3758/s13428-016-0727-z

Milne, A. E., Bianco, R., Poole, K. C., Zhao, S., Oxenham, A. J., Billig, A. J., & Chait, M. (2021). An online headphone screening test based on dichotic pitch. *Behavior Research Methods*, *53*(4), 1551–1562. https://doi.org/10.3758/s13428-020-01514-0

Neger, T. M., Rietveld, T., & Janse, E. (2014). Relationship between perceptual learning in speech and statistical learning in younger and older adults. *Frontiers in Human Neuroscience*, *8*, 628. https://doi.org/10.3389/fnhum.2014.00628

Nemeth, D., Janacsek, K., Polner, B., & Kovacs, Z. A. (2013). Boosting human learning by hypnosis. *Cerebral Cortex (New York, N.Y.: 1991)*, *23*(4), 801–805. https://doi.org/10.1093/cercor/bhs068

Peng, J., Lu, H., Zhang, J., Shao, Y., Wang, L., & Lv, J. (2022). Need for cognition moderates the impairment of decision making caused by nightshift work in nurses. *Scientific Reports*, *12*(1), Article 1. https://doi.org/10.1038/s41598-022-05843-2

Perruchet, P., & Pacton, S. (2006). Implicit learning and statistical learning: One phenomenon, two approaches. *Trends in Cognitive Sciences*, *10*(5), 233–238. https://doi.org/10.1016/j.tics.2006.03.006

Rodríguez, M., & Sadoski, M. (2002). Effects of Rote, Context, Keyword, and Context/Keyword Methods on Retention of Vocabulary in EFL Classrooms. *Language Learning*, *50*, 385–412. https://doi.org/10.1111/0023-8333.00121

Romberg, A. R., & Saffran, J. R. (2010). Statistical learning and language acquisition. *WIREs Cognitive Science*, *1*(6), 906–914. https://doi.org/10.1002/wcs.78

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science (New York, N.Y.)*, *274*(5294), 1926–1928. https://doi.org/10.1126/science.274.5294.1926

Schertz, K. E., & Berman, M. G. (2019). Understanding Nature and Its Cognitive Benefits. *Current Directions in Psychological Science*, *28*(5), 496–502. https://doi.org/10.1177/0963721419854100

Schevenels, K., Altvater-Mackensen, N., Zink, I., De Smedt, B., & Vandermosten, M. (2021). Aging effects and feasibility of statistical learning tasks across modalities. *Aging, Neuropsychology, and Cognition*, *0*(0), 1–30. https://doi.org/10.1080/13825585.2021.2007213

Siegelman, N., Bogaerts, L., Elazar, A., Arciuli, J., & Frost, R. (2018). Linguistic entrenchment: Prior knowledge impacts statistical learning performance. *Cognition*, *177*, 198–213. https://doi.org/10.1016/j.cognition.2018.04.011

Smalle, E. H. M., Daikoku, T., Szmalec, A., Duyck, W., & Möttönen, R. (2022). Unlocking adults' implicit statistical learning by cognitive depletion. *Proceedings of the National Academy of Sciences*, *119*(2), e2026011119. https://doi.org/10.1073/pnas.2026011119

Tran, Y., Wijesuriya, N., Tarvainen, M., Karjalainen, P., & Craig, A. (2009). The relationship between spectral changes in heart rate variability and fatigue. *Journal of Psychophysiology, 23*(3), 143–151. https://doi.org/10.1027/0269-8803.23.3.143

Turk-Browne, N. B., Jungé, J., & Scholl, B. J. (2005). The automaticity of visual statistical learning. *Journal of Experimental Psychology. General*, *134*(4), 552–564. https://doi.org/10.1037/0096-3445.134.4.552

Uddén, J., Folia, V., Forkstam, C., Ingvar, M., Fernandez, G., Overeem, S., van Elswijk, G., Hagoort, P., & Petersson, K. M. (2008). The inferior frontal cortex in artificial syntax processing: An rTMS study. *Brain Research, 1224*, 69–78. https://doi.org/10.1016/j.brainres.2008.05.070

Ullman, M. T. (2004). Contributions of memory circuits to language: The declarative/procedural model. *Cognition*, *92*(1–2), 231–270. https://doi.org/10.1016/j.cognition.2003.10.008

Ullman, M. T. (2006). Is Broca's area part of a basal ganglia thalamocortical circuit? *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, *42*(4), 480–485. https://doi.org/10.1016/s0010-9452(08)70382-4

van Hell, J. G., & Mahn, A. C. (1997). Keyword Mnemonics Versus Rote Rehearsal: Learning Concrete and Abstract Foreign Words by Experienced and Inexperienced Learners. *Language Learning*, *47*(3), 507–546. https://doi.org/10.1111/0023-8333.00018

Virag, M., Janacsek, K., Horvath, A., Bujdoso, Z., Fabo, D., & Nemeth, D. (2015). Competition between frontal lobe functions and implicit sequence learning: Evidence from the long-term effects of alcohol. *Experimental Brain Research*, *233*(7), 2081–2089. https://doi.org/10.1007/s00221-015-4279-8

Ward, E. V., Berry, C. J., & Shanks, D. R. (2013). Age effects on explicit and implicit memory. *Frontiers in Psychology*, *4*, 639. https://doi.org/10.3389/fpsyg.2013.00639

Webb, S., Yanagisawa, A., & Uchihara, T. (2020). How Effective Are Intentional Vocabulary-Learning Activities? A Meta-Analysis. *The Modern Language Journal*, *104*(4), 715–738. https://doi.org/10.1111/modl.12671

Woo, S. E., Harms, P. D., & Kuncel, N. R. (2007). Integrating personality and intelligence: Typical intellectual engagement and need for cognition. *Personality and Individual Differences*, *43*(6), 1635–1639. https://doi.org/10.1016/j.paid.2007.04.022

Yang, Y., Chen, M., He, W., & Merrill, E. C. (2020). The Role of Working Memory in Implicit Memory: A Developmental Perspective. *Cognitive Development*, *55*, 100929. https://doi.org/10.1016/j.cogdev.2020.100929

Curriculum Vitae

Name:	Mark Dunlop
Place and Year of Birth:	Canada, 1988
Post Secondary School Diploma:	Liberal Studies, Lambton College, Sarnia, Canada
Scholarships:	Transfer Student Scholarship 2016 in the amount of $1500
Awards:	Deans Honors List 2017, 2019
Experience:	Huron University CURL Spring Conference (2023)