On the Temporal Onset of Irrelevant Sequence Learning

Ryan J. Brady

University of North Carolina at Chapel Hill

Advisor: Dr. Kelly Giovanello

April 08, 2014

Dr. Kelly Giovanello ____________________________

Mr. Chris Foster ____________________________
On the automaticity of irrelevant sequence learning

Abstract:

Prior studies have investigated the degree of automaticity involved in implicit sequence learning. Deroost et al. (2008) used the Serial Reaction Time (SRT) task to show that participants can implicitly acquire sequence specific knowledge of a complex relevant sequence, while concurrently learning an equally complex irrelevant sequence they are told to ignore. However it is not known whether or not irrelevant sequence learning relies on the availability of cognitive resources. The current study investigated the temporal onset of irrelevant sequence learning by measuring the amount of irrelevant information learned at different time points during the SRT task. In Experiment 1, participants were presented with a complex second order relevant sequence and a simple first order irrelevant sequence and learning was measured after 7 and 12 blocks in separate groups. In Experiment 2, participants were presented with a complex second order sequence for both relevant and irrelevant stimuli, and learning was measured after 14 and 19 blocks in separate groups. Results from Experiment 1 showed that learning of an irrelevant first order sequence began early and became solidified by blocks 7 and 12. In Experiment 2, learning of a second order irrelevant sequence was not completed by 14 blocks as indicated by a negative priming effect. However, learning of the irrelevant second order sequence became solidified by 19 blocks, as indicated by the lack of the negative priming. Our results are consistent with the suggestion that implicit sequence learning is highly automatic, as long as selective attention is drawn to the predictive dimension. The results of the current study also offer insight into the findings of Deroost et al. (2008) by suggesting that independent learning of an irrelevant sequence does not rely on availability of cognitive resources.
Acknowledgements

I would like to thank Dr. Kelly Giovanello, Chris Foster and the Cognitive Neuroscience of Memory Lab at UNC for the tremendous amount of help and feedback they have given me. Thank you to Priyanka Barad and Maragret O’Brien for assisting in data collection. I would also like to thank Dr. Neil Mulligan for serving as a committee member and the honors department of Psychology at UNC for providing this opportunity.
On the Automaticity of Irrelevant Sequence Learning

A key evolutionary development of cognition is the ability to detect regularities in the environment. Being sensitive to changes in the environment allows an organism to predict future outcomes and adjust its behavior accordingly, whether it be through conscious or unconscious processes. As humans perceive time in a linear manner, the serial organization of these regularities is not only essential to human functioning, but also inevitable. Examples from everyday life that illustrate the importance of serial organization can be seen in the sequencing of actions while driving, playing sports, or while sequencing sounds in language and music (Coomans et al., 2011). However, with the myriad of information that is flooded into our perceptual system, it is impossible to account for the vast number of associations as happening within our conscious scope. Consequently, many of these sequential relations seem largely obtained through unintentional learning which results in knowledge that is hard to access consciously, a process referred to as implicit learning (Cleeremans, Destrebecqz & Boyer, 1998; Clegg, DiGirolamo & Keele, 1998).

Implicit Learning and the Serial Reaction Time Task

Implicit learning has typically been defined as the acquisition of knowledge that takes place independent of conscious attempts to learn, and largely in the absence of explicit knowledge of what has been acquired (Reber, 1993). Because of its core function in human cognition, implicit sequence learning, and its underlying mechanisms, has long been an area of research in cognitive psychology. Nissen and Bullemer (1987) developed the Serial Reaction Time (SRT) task which has been adopted as the prototypical paradigm to study implicit sequence learning. In the standard SRT task, participants are instructed to respond as quickly and as accurately as possible to a stimulus appearing in one of four locations. They are not informed that the successive stimuli are presented following a regular sequence structure, which is continuously repeated over trials. Participants’ acquisition of sequence-specific
knowledge can be inferred from a decrease in reaction time with practice and an increase in reaction time with a temporary interruption of the regular sequence (Deroost et al., 2008). Since the sequenced information in the SRT task is acquired incidentally, and is hard to verbalize in awareness tests administered after training, the task is considered an appropriate tool to investigate implicit learning (Coomans et al., 2011).

The Automaticity of Implicit Learning and the Role of Attention

As implicit learning takes place unconsciously, it has been suggested that it is accomplished through automatic learning mechanisms (Cleeremans & Jimenez, 1998; Frensch, 1998; Perruchet & Gallego, 1997). The role of attention during sequence learning has become a key question in research in hopes of answering the automaticity question. The relationship between automaticity and attentional resources derives from the assumption that attentional processing is limited by central resources that should be shared among all concurrent tasks, whereas automatic processing does not use a pool of resources (Cowan, 1988). Schneider and Shiffrin (1977) claimed that a process should be considered automatic if it (a) does not use general processing resources (i.e., lack of mental effort) or (b) runs independent of attentional control (i.e., lack of selective attention). In line with premise (a), Hasher & Zacks (1984) put forth the idea that a key criterion of automaticity is effortlessness. Effortlessness in this sense means requiring a minimal amount of attentional capacity. Therefore, if implicit sequence learning is a truly automatic process, it can be operationalized as learning that places minimal demands on attention (Coomans et al. 2011). In line with premise (b), the view of attention as a selective process puts forth the idea that if implicit learning is automatic, it does not need to be selectively initiated or monitored, but rather is simply prompted by external stimulus input.

Previous studies have addressed these two avenues of automaticity using two main types of paradigms, both involving the SRT task. To address the necessity of attentional resources, it is common
to divide attention during an SRT task and assess the effect on implicit learning. To investigate the necessity of selective attention, it has been common to manipulate participant’s attention to (or from) the predictive dimension of an SRT task. Both paradigms will be explained in the following sections.

**Selective Attention**

The term *dimension* has generally been used interchangeably with modality (i.e. visual, spatial, or auditory information) (Keele et al. 2003). Previous studies have illustrated that a lack of attention to the predictive dimension of the SRT task results in a large deficit in sequence learning (Jimenez, Mendez & Lorda, 1993; Jimenez and Mendez (1999) showed this result by using a dual-task SRT paradigm that forced participants to simultaneously attend to two predictive dimensions. In their experiment, participants responded to one of four possible stimuli shapes (x,*,?,!) appearing at one of four locations, arranged horizontally on a computer screen. Participants were instructed to press as quickly and as accurately as possible the key corresponding to the current location of the stimulus. Two concurrent sequences were interacting: the probabilistic sequence of location and the sequential relationship between the stimulus shapes. To test the acquisition of these relationships, the experimenters divided participants into either a single-task condition or a dual-task condition. In the single-task condition, participants were told to respond to the location of the stimulus regardless of shape, as it appeared on the screen. In the dual task condition, participants were required to respond to the location of the stimulus, while additionally instructed to keep a running count of the number of trials in which two prior target shapes appeared. For instance if the target shapes were “x” and “*”, participants would have to keep a running count of how many times those shapes appeared within the SRT task to report at the end of each block. With this design, the experimenters were able to simultaneously test two effects: 1) the effect of dividing attention while learning a complex sequence of location, and 2) the effect of directing selective attention to the predictive dimension of shape which would be present in the dual task.
condition and not the single task condition. Results indicated that participants in the single task condition only showed learning of the complex sequence of locations. However participants in the dual task condition who were forced to selectively attend to the target shapes, showed learning of the relationship between both shapes and location.

Such findings are interesting because they satisfy one, but not both, of the criterion of an automatic processes defined earlier by Schnider and Shiffrin (1977). The fact that learning was not impaired in the dual task condition is in line with the idea that implicit learning is automatic and does not depend on availability of attentional resources. However, the fact that participants only learned information in the dimension in which they paid attention to suggests that implicit learning does not automatically associate all perceptual input in a completely nonselective way. Attending to a predictor may be necessary to maintain its representation long enough to enable it to become associated with the next event (Jimenez & Mendez, 1999). Subsequent studies have confirmed that selective attention is necessary for sequence learning to occur (Hoffmann & Sebald, 2005). In general, it is agreed that the sequenced target information must be in the attentional focus for sequence learning to occur (Coomans et al., 2011).

**Attentional Resources**

Many studies have also analyzed the effects of limited attentional resources on sequence learning by including a secondary task that participants must complete, while simultaneously responding to the SRT task. Most studies have used a tone-counting secondary task in which different pitched tones are presented along with the sequence information and participants are told to keep track of the number of tones heard. Such studies typically do not find an effect of the secondary task on sequence learning (Cohen, Ivry & Keele, 1990; Curran & Keele, 1993; Frensch, Lin & Buchner, 1998).
Along these lines, a study performed by Jimenez and Mendez (1999) showed that dividing participants’ attention when both tasks are within the same dimension did not have a detrimental effect on learning. Thus, the automaticity view was supported. However, Shanks, Rowland and Ranger (2005), who used a task comparable to Jimenez and Mendez (1999) did observe a detrimental effect of the secondary task on sequence learning. According to the authors, the long training participants received in the Jimenez and Mendez (1999) study likely led to the secondary task becoming automatized over time, rendering more attentional capacity available for learning the location sequence. In conclusion, although there is a general agreement that sequenced information needs to be selectively attended to, whether or not learning in an SRT task is impaired by a secondary task remains unclear (Coomans et al. 2011).

In an attempt to address this question, Coomans et al. (2011) performed a study to investigate the effects of perceptual load on sequence learning by adding a visual search component to the SRT task. Previous studies have used a secondary task separate from the SRT task like shape counting, or tone counting, to investigate how the availability of cognitive resources affects sequence learning. However, in this paradigm, by using the visual distracters to make perception of the target stimuli harder, authors were able to avoid using a secondary task while still manipulating cognitive load. The task was a purely perceptual sequence learning task (i.e., sequence learning without a structure placed on the response dimension) and only the perceptual dimension was structured according to a sequence. Participants were thus forced to devote attention to the visual information as motor responses contained no structure (Coomans et al., 2011). Perceptual load was manipulated in three conditions: Participants saw the target either alone (no load), with distractors that were easy to discriminate from the target (low load), or with distractors similar to the target (high load). Selective attention to the target was required to identify and respond to it among the distractors, but the amount of perceptual load varied based on the condition. It was hypothesized that if implicit sequence learning reflects an
automatic process, than an equal amount of sequence learning should be observed in all conditions, regardless of perceptual load during acquisition. The results indicated that perceptual load did not contribute in any way to the acquisition of implicit sequence knowledge, thus supporting the notion of implicit sequence learning as an automatic process that runs independent of attentional resources.

The Negative Priming Effect and Sequence Learning

The negative priming effect is observed when a stimulus that was irrelevant on a prior trial, becomes relevant on a subsequent trial (Cock et al., 2002). Responses to this subsequent trial are typically impaired compared to responses to stimuli that were not previously presented. Tipper (1985) performed a study in which participants viewed a prime display consisting of a red line drawing superimposed over a green one, and were asked to name the red drawing. The subsequent display consisted of a red drawing superimposed over a green one and participants were again asked to name the red drawing. In one experimental condition, the second trial consisted of a green drawing that was the outline of the red drawing of the first trial. The results showed significantly longer reaction times to name the red drawing in this condition, and thus illustrated negative priming.

Cock et al. (2002) performed a study to investigate the negative priming effect during the SRT task. The point of the study was to address the question of whether or not negative priming effects can extend beyond learning of individual items (i.e. Tipper, 1985), and be shown in continuous sequence learning tasks. The authors used a dual-sequence SRT task in which participants responded to a “relevant” stimulus appearing on a screen in one of four locations in a patterned sequence. Concurrently, a second “irrelevant” stimulus which participants were instructed to ignore, appeared on the screen within the same four locations. This irrelevant sequence followed a different patterned sequence equal in complexity. It was hypothesized that if participants are responding to one patterned sequence while ignoring another, they will learn something about the ignored sequence to effectively
inhibit the to-be-ignored information (Cock et al., 2002). The results supported this hypothesis, as participants’ reaction time was significantly disrupted when they were asked to respond to the previously ignored sequence compared to a condition in which they were asked to respond to a novel sequence.

A study by Deroost and colleagues (2008) expounded upon the findings of Cock et al. (2002) by using the dual-sequence SRT task to further investigate the mechanisms underlying negative priming in sequence learning. In Deroost et al. (2008), authors used 12 item second order sequence structures that were more balanced and more complex in nature than in Cock et al. (2002) who used 6 item sequences that did not contain any higher order information. This allowed authors to find out if the negative priming effect applies to complex sequential material. Deroost et al. (2008)’s paradigm consisted of 12 blocks of learning trials in which both relevant and irrelevant stimuli sequences were presented, and then participants transferred to a testing phase in which the relevant stimuli switched to then implement the sequence of the previously irrelevant stimuli. The results indicated that participants in a condition who were later asked to respond to the previously irrelevant sequence showed a significant disruption in reaction time compared to participants who were later asked to respond to a random sequence. The observation of negative priming in this experiment illustrated that, while actively ignoring the irrelevant sequence, participants implicitly acquired complex sequence knowledge of the irrelevant stimuli.

An important finding from this study was that the irrelevant sequence could be learned completely independent of the relevant sequence. However since the irrelevant and relevant stimuli appeared at the same time, it could be argued that participants were simply associating the relevant stimuli locations with the irrelevant stimuli locations and learning them both as one. In a second experiment, experimenters addressed this issue by phase shifting the irrelevant sequence after each
block, such that the irrelevant sequence started at a different position in the pattern. Under these conditions, without the possibility of participants associating the two stimuli together, a significant negative priming effect was still observed for the irrelevant sequence. The findings of this study indicate that learning of an irrelevant sequence can occur independently of a relevant sequence (Deroost et al., 2008). In a third experiment, participants responded to a random relevant sequence while the irrelevant sequence, remained structured. Under these conditions, no NP effect was observed for the irrelevant sequence, and it was concluded that learning of an irrelevant sequence requires a structured relevant sequence.

To explain these findings, Deroost et al. (2008) suggested that learning predictable information of the relevant stimuli released sufficient attentional resources that could then be deployed to learning of the irrelevant information. Alternatively, and in line with the suggestion of Jimenez and Mendez (1999), it could be that learning of the relevant sequence initiated learning of other stimuli within the same predictive dimension, which in this case was the otherwise unnoticed irrelevant sequence information. Hence, irrelevant sequence learning may rely on the amount of attentional resources available, or simply on the selective recognition of a dimension as containing predictive information.

The Current Study

At present, it is generally agreed that selective attention to the predictive dimension during a SRT task is necessary for implicit sequence learning (Jimenez & Mendez, 1999). Coomans et al. (2011) suggests that implicit sequence learning is automatic by illustrating that implicit learning in a purely perceptual SRT task is not affected by perceptual load limits. Meanwhile, Deroost et al. (2008) illustrated that implicit learning of an irrelevant sequence in an SRT task may be due to reliance on the availability of cognitive resources which suggests that this process is not automatic. With the present information, the degree of automaticity involved in implicit sequence learning is not fully understood.
When presenting a relevant sequence simultaneously with an irrelevant sequence, there are two possible patterns of results: 1) In line with the automatic view of implicit learning, the irrelevant sequence will be learned concurrently with the relevant sequence. Thus, if both sequences are of equal complexity, the rate of learning should asymptote at the same time. 2) In contrast to the automaticity view, learning of the irrelevant sequence relies on resources being freed as learning of the relevant sequence progresses. Thus, irrelevant sequence knowledge should be acquired after learning of the relevant sequence knowledge begins.

The current study used the relevant/irrelevant SRT paradigm employed by Deroost et al. (2008) to understand how irrelevant sequence learning takes place implicitly. Knowing when an irrelevant sequence is being learned in relation to a relevant sequence provides novel insight into the attentional mechanisms that are responsible for implicit sequence learning. Thus, we conducted two experiments to investigate the temporal onset of irrelevant sequence learning.

**Experiment 1**

Experiment 1 was designed to investigate the presence of negative priming at two time points when participants are responding to a second order relevant sequence, and ignoring a first order irrelevant sequence. We used the relevant/irrelevant SRT paradigm from the Deroost et al. (2008) study, and had two groups: In an “early” group, participants transferred to the testing phase after 7 blocks of learning, and in a “late” group, participants transferred to the testing phase after 12 blocks of learning. These two groups allowed for the comparison of negative priming between an early time point and a later time point. Within both the early and late groups, participants were randomly assigned to one of two conditions: In the “transfer to irrelevant” (hereafter called TTI) condition, the testing phase stimuli followed the pattern of the previously irrelevant stimuli. In the “transfer to novel” (hereafter called TTN) condition, the testing phase stimuli followed the pattern of a novel sequence with equal
complexity as the irrelevant sequence. The two conditions served to identify the negative priming effect. The negative priming effect occurs when SRT performance becomes significantly impaired when participants respond to a sequence they were previously ignoring (TTI condition), compared to a novel sequence (TTN condition).

The different lengths of learning blocks for the early and late groups (7 & 12), were chosen because previous research (Cherry & Stadler, 1995; Dennis, et al., 2006; Kelly et. al, 2004) has shown that implicit learning of a first order sequence when the information is relevant, will occur in the SRT task at least by seven blocks of 80 trials. Thus, as the irrelevant sequence is following a first order pattern for experiment 1, we choose to test for negative priming after 7 blocks of learning. The presence of negative priming would indicate that participants had acquired some knowledge of the irrelevant sequence. Furthermore, the inclusion of the late group who transfer after 12 blocks of learning was implemented to possibly identify a temporal lag in the onset of irrelevant learning.

We hypothesized that if implicit sequence learning occurs automatically and independent of attentional resources, learning of the irrelevant sequence should asymptote after seven blocks of learning and the negative priming effect observed at transfer between the early and late groups should not be significantly different. Alternatively, if implicit sequence learning is not automatic and learning the relevant sequence releases attentional resources to then allow for learning the irrelevant sequence, we should expect to see a significant difference in the degree of negative priming at transfer between the early and late group.

Methods

Participants

Thirty-two (40 women and 24 men) of the University of North Carolina at Chapel Hill (UNC) participated in return for course credit. Their mean age was (M= 19.03 years, SD = .99). This was the
case for both experiments. Participants were randomly assigned to either the early or late group, and to either of the two conditions.

Stimuli and Apparatus.

Participants were tested individually in the cognitive neuroscience of memory lab at UNC. The SRT task was run on Dell lap-top computer with 17 inch screen using E-Prime Version 2.0 (Psychology Software Tools, Inc). The relevant sequence was a red “+” appearing against a white background within one of four white circles presented horizontally in a row. The irrelevant sequence stimulus was a blue “x” and appeared simultaneously with the relevant stimuli. The two colors were counterbalanced across conditions. The location of the stimuli never repeated consecutive positions and if the two sequences ever overlapped in presentation within one of the circles, the relevant stimuli would appear on top of the irrelevant stimuli with only the middle intersection overlapping. The leftmost, left, right and rightmost circles represented the four possible stimulus locations, mapped onto the “z”, “c”, “,” and “/” response keys on the bottom row of a standard keyboard, and indicated with a felt cover.

The simple first order sequence was twelve digits long and there were two versions counter balanced across conditions (312421343142, and 423132414213). A first order sequence is a sequence in which the probability of the next location occurring lies in the number one position before it. The complex second order sequence used in the current study was twelve digits long. There were two versions counter balanced across conditions (121342314324 and 212431423413). Learning of a second order sequence is more complex because it requires knowledge of the previous two positions in order to predict the next, and thus, is highly complex in nature (Deroost et al. 2008). One important characteristic of the second order sequence used in the current study is that all location alternatives occur equally often and each alternative is equally often followed by all other alternatives (e.g., 1 is
always equally often followed by alternatives 2, 3 and 4). This is important because as each number is represented equally in the pattern, there is no first order information participants can pick up on.

*Design and Procedure.*

Participants were instructed to respond as quickly and as accurately as possible to the relevant sequence (e.g. the red “+”) while ignoring the irrelevant sequence (e.g. the blue “x”) using their middle and index finger on each hand. The relevant and irrelevant stimuli were displayed and would not proceed until a response was given. The four circles marking the stimulus locations remained on the screen throughout each block of trials. The next trial began after a response-stimulus interval of 50 ms. Reaction times and accuracy were recorded on each trial. The SRT task consisted of: practice trials, learning trials, testing trials, and a questionnaire for awareness.

*Practice trials* consisted of one block of 48 trials. During practice, the location of the relevant and irrelevant stimuli changed according to different sequences that were generated through with the constraint that no stimulus would repeat consecutive locations. After practice, participants were informed that the actual experiment was going to begin.

*Learning trials* consisted of 7 blocks in the early group, and 12 blocks in the late group. Each block started with 4 random trials and then 8 cycles of the 12 item sequence. After each block of trials, participants received feedback about their accuracy and average reaction times for that particular block on a screen that would last for 30 seconds. The next block would begin without prompt after the 30 seconds.

*Testing Trials* consisted of 3 blocks after the learning trials. During these blocks however, only the relevant stimuli appeared on the screen while participants responded. In the testing trials, the
sequence either followed the previously ignored pattern or a novel pattern that the participant had not previously encountered. (See figure 1)

![Learning Trials](image1)
![Testing Trials](image2)

*Figure 1*

Following the completion of the testing trials, a questionnaire for awareness was administered. The questionnaire adopted from Willingham et al. (2003), consisted of 6 questions designed to probe for overall awareness of experimental design, and most importantly to assess any explicit memory of the sequences. Each question was scored in a binary form except for question 3 which had a maximum score value of 2. Any participant who scored 7/7 on the questionnaire was deemed “aware” and was excluded from data analysis. The exact questionnaire as well as a rubric for scoring can be found in the appendix.

**Results**

The results section is organized by separate analyses for 1) the learning phase (blocks 1-7), in which the relevant stimulus was presented concurrently with the irrelevant stimulus, and 2) the testing phase for each group which occurred after transfer(8-10 and 13-15 respectively), 3) the transfer blocks
for each group from learning to testing, (7-8 and 12-13 respectively). All analyses were performed on the mean median RTs per block. Erroneous responses were also excluded from the RT analyses.

Based on the questionnaire for awareness, zero participants showed explicit knowledge of the sequences that would warrant them to be being excluded. Participants’ mean awareness score out of 7 was \( M = 2.19, SD = 1.6 \) in the early group TTI condition, \( M = 1.81, SD = 1.33 \) in the early group TTN condition, and \( M = 2.44, SD = 1.50 \) in the late group TTI condition. \( M = 3.44, SD = 1.50 \) in the late group TTN condition. There was no main effect of condition \( F(1,60) = 3.42, \text{MSE} = 7.563, p = .07 \). There was a main effect of group \( F(1,60) = 6.36, \text{MSE} = 14.06, p = .014 \). The Group x Condition interaction was not significant \( F(1,60) = .706, \text{MSE} = 1.56, p = 0.4 \).

**Learning phase (blocks 1-7)**

It is important to note that because the late group has a learning phase that is 5 blocks longer than the early group, the analysis of RTs of the learning phase for the late group only includes blocks 1-7 as such is the learning phase of the early group.

**Accuracy**

Participants’ accuracy rate was above 95% in all four conditions: The average accuracy score per block amounted to \( M = 98\%, SD = 0.0074 \) in the early group TTI condition, \( M = 98\%, SD = 0.0064 \) in the early group TTN condition, and \( M = 97\% SD = 0.0054 \) in the late group TTI condition, \( M = 97\%, SD = 0.0081 \) in the late group TTN condition. The accuracy was high throughout the experiment and thus, this measurement was not analyzed.

**Reaction Times (RTs).**

A repeated-measures ANOVA was carried out with condition and group as between-subjects factors and block as a within-subjects factor. This analysis showed that RTs decreased significantly over
On the automaticity of irrelevant sequence learning

blocks, $F(6,360) = 91.97$, $MSE = 39,962$, $p < .001$ (see figure 2). There was neither a main effect of group, $F(1,60) = .913$, $MSE = 22105$, $p = .88$, nor a main effect of condition, $F(1,60) = .02$, $MSE = 536$, $p = .343$. Additionally, the interaction of block x condition was not significant, $F(6, 360) = 1.90$, $MSE = 274.29$, $p = .705$. Finally, the RT decrease was similar in all conditions and between groups: The Condition x Block x Group interaction was not significant, $F(6, 360) = .464$, $MSE = 201$, $p = .835.

Testing Phase (8-10, 13-15)

Accuracy

Participants’ accuracy rate was above 95 % in all four conditions: the average accuracy score across blocks was ($M = 95\%, SD = 0.0036$) in the early group TTI condition, ($M = 96\%, SD = 0.0119$) in the early group TTN condition, and ($M = 97\%, SD = 0.0037$) in the late group TTI condition, ($M = 96\%, SD = 0.0055$) in the late group TTN condition.

RTs

A repeated-measures ANOVA with condition and group as between-subject factors and block as within-subjects factor showed that there was a main effect of block indicating that RTs decreased over blocks, $F(2,120) = 43.85$, $MSE = 11719$, $p<.001$. There was neither a main effect of group, $F(1,60) = 2.85$, $MSE = 15114$, $p = .096$, nor a main effect of condition, $F(1,60) = .59$, $MSE = 3103$, $p = .45$. There was no interaction between block and condition, $F(2,120) = .16$, $MSE = 42.859$, $p = .852$. The Block x Condition x Group was not significant $F(2,120) = .547$, $MSE = 146$, $p = .58.

Transfer Blocks (7-8, 12-13)

The analysis of transfer from the learning phase to testing phase is important, as learning of the irrelevant sequence in TTI condition is inferred from a greater increase in RT during transfer, compared
to the TTN condition. To observe that negative priming has occurred, participants must be more disrupted when transferring to a previously irrelevant sequence, as compared to participants in the TTN condition that transfer to a novel sequence with equal complexity.

**Errors**

Participants’ accuracy rate was above 95 % in all four conditions: The average accuracy score per block was \((M = 96\%, SD = 0.0129)\) in the early group TTI condition, \((M = 96\%, SD = 0.0212)\) in the early group TTN condition, and \((M = 96\%, SD = 0.0157)\) in the late group TTI condition, \((M = 95\%, SD = 0.0095)\) in the late group TTN condition.

**RTs**

A repeated-measures ANOVA with condition and group as between-subjects factors and block as a within-subjects factor showed a main effect of block indicating that RTs increased significantly when transferring from block 7 to 8 (early group) and block 12 to 13 (late group), \(F (1,60) = 45.5, MSE = 55029, p < .001\). There was a main effect of group, \(F (1,60) = 9.1, MSE = 50696, p = .004\) however there was not a main effect of condition, \(F(1,60) = .19, MSE = 1108, p = .66\). The increase in transfer interacted significantly with group, \(F(1,60) = 21.04, MSE = 25446, p < .001\). However the interaction of block x condition was not significant, \(F(1,60) = .335, MSE = 405, p = .565\), indicating that there was no difference in transfer between conditions. Furthermore, the Block x Condition x Group was not significant, \(F (1,60) = .048, MSE = 57, p = .828\).
The results of Experiment 1 showed that participants in both early and late groups, whether in TTI condition or TTN condition displayed similar SRT performance during blocks 1-7. The most important information however lies in the analysis of transfer from the learning phase to the testing phase. In both groups, the transfer to the testing phase whether it was to a previously irrelevant sequence or to a novel sequence produced a significant increase in RT. However, in both the early and late group, there was no difference in the increase in RT between conditions. Thus, no negative priming was found in either the early or late group.

In sum, the results of Experiment 1 show that responding to a previously irrelevant first order sequence after 7 blocks of 100 trials and after 12 blocks of 100 trials had significant disruption in SRT performance however no negative priming effect was found. There are two possible explanations of Experiment 1: 1) Participants did not learn the irrelevant sequence during the learning blocks and thus
no negative priming occurred; or 2) Participants completed learning of the irrelevant sequence during the learning blocks and thus, the significant disruption usually produced by negative priming disappeared. It is important to note that Deroost et al. (2008) showed negative priming with a second order irrelevant sequence after 12 blocks of learning, and the current experiment does not show negative priming with a less complicated first order sequence after 12 blocks of learning. Thus, it is likely that the absence of negative priming seen in both the early and late group of experiment 1 indicates that irrelevant learning was completed. Such a conclusion would support the automatic view that irrelevant sequence learning began early and at the same time of the relevant sequence. However, to adjudicate between these two explanations, the results of Experiment 1 must be taken in compliment with the results of Experiment 2.

**Experiment 2**

Experiment 1 investigated the temporal onset of a first order irrelevant sequence. Experiment 2 was designed to investigate the temporal onset of a second order irrelevant sequence. Previous studies have shown that participants can learn a second order irrelevant sequence by 12 blocks of 100 trials (Deroost et al., 2008). We sought to replicate this finding by having an “early” group transfer after 14 blocks of learning, while including a “late group” in which participants transfer after 19 blocks of learning. Additionally, this design provided an opportunity to explore the question raised in Experiment 1 of how to explain the absence of negative priming. After 19 blocks, participants have had substantially more time to learn the sequence compared to the “early” group in which the literature indicates should produce negative priming. Thus, if negative priming occurs in the early group, and not in the late group, such results would provide strong support for the notion that the absence of negative priming can indicate that participants have completed learning.

**Methods**
Participants.

Sixty-four (39 women and 25 men) of the University of North Carolina at Chapel Hill (UNC) participated in return for course credit. Their mean age was \( M = 19.4 \) years, \( SD = 1.6 \). Participants were randomly assigned to each group and each condition.

Stimuli and Apparatus.

The apparatus was the same as in experiment 1. The only change was in the sequence of the irrelevant stimuli which now follows a complex second order sequence. The complex second order sequences used in the current study were twelve digits long and were one of four possibilities that were counter balanced across conditions (121342314324, 212431423413, 323421431241, and 414231243213).

Design and Procedure.

The design and procedure is exactly the same as experiment 1 with the change that the learning trials were 14 blocks long in the early group and 19 blocks long in the late group.

Results

Based on the questionnaire for awareness, 4 of the 64 participants showed explicit knowledge of the sequence and were excluded from data analysis. Of these 4 participants, 1 was excluded from the early group TTI condition, 1 from the late group TTI condition, and 2 from the late group TTN condition. Participants’ mean awareness was \( M = 3.3, SD = 1.75 \) in the early group TTI condition, \( M = 2.9, SD = 1.44 \) in the early group TTN condition, and \( M = 3.9, SD = 1.88 \) in the late group TTI condition, \( M = 3.3, SD = 1.69 \) in the late group TTN condition. There was no main effect of condition \( F (1,60) = .33, MSE = 1.26, p = .57 \). There was no main effect of group \( F (1,60) = 2.58, MSE = 9.76, p = .11 \). The Group x Condition interaction was not significant \( F (1,60) = .49, MSE = 1.89, p = .48 \).
Learning phase (blocks 1-14)

Since the late group had a learning phase that is 5 blocks longer than the early group, the analysis of RTs of the learning phase for the late group includes only blocks 1-14.

Accuracy

Participants’ accuracy rate was above 95% in all four conditions: The average accuracy score per block was ($M = 97\%$, $SD = 0.0080$) in the early group TTI condition, $M = 97\%$ ($SD = 0.0060$) in the early group TTN condition, ($M = 97\%$, $SD = 0.0070$) in the late group TTI condition, and ($M = 97\%$, $SD = 0.0050$) in the late group TTN condition. The accuracy was high throughout the experiment and thus, this measurement was not analyzed statistically.

Reaction Times (RTs).

A repeated-measures ANOVA was conducted with condition and group as between-subjects factors and block as a within-subjects factor. This analysis showed that RTs decreased significantly over blocks, $F(11,660) = 120.7$, $MSE = 73347$, $p < .001$. There was a main effect of condition, $F(1,60) = 8.8$, $MSE = 277461$, $p = .004$. However there was no main effect of group, $F,(1,60) = .002$, $MSE = 67.5$, $p = .963$. The interaction of block x condition was not significant, $F(11, 660) = .513$, $MSE = 311.8$, $p = .895$. Furthermore, the RT decrease was similar in all conditions and between groups: The Condition x Block x Group interaction was not significant, $F(11, 660) = .699$, $MSE = 424.9$, $p = .74$.

Testing Phase (8-10, 13-15)
Accuracy

Participants’ accuracy rate was above 94% in all four conditions: The average accuracy score per block was ($M = 95\%, \ SD = 0.0077$) in the early group TTI condition, ($M = 95\%, \ SD = 0.0129$) in the early group TTN condition, ($M = 94\%, \ SD = 0.0176$) in the late group TTI condition, and ($M = 95\%, \ SD = 0.0112$) in the late group TTN condition.

RTs

A repeated-measures ANOVA with condition and group as between-subject factors and block as a within-subjects factor showed that there was a main effect of block indicated that RTs decreased over blocks, $F(2,112) = 32.98$, $MSE = 5681$, $p<.001$. There was neither a main effect of group, $F,(1,60) = .135$, $MSE =580$, $p = .715$, nor a main effect of condition, $F (1,60) = .322$, $MSE = 1385$, $p = .572$. There was no interaction between block and condition, $F(2,112) = .837$, $MSE = 144.2$, $p = .436$. Moreover, the Block x Condition x Group was not significant $F(2,112) = .1.77$, $MSE = 304$, $p = .18$, indicating that the decrease in reaction time was not different across all conditions.

Transfer Blocks (14-15, 19-20)

Errors

Participants’ accuracy rate was above 90% in all four conditions: The average accuracy score per block amounted to ($M = 95\%, \ SD = 0.0128$) in the early group TTI condition, ($M = 95\%, \ SD = 0.0226$) in the early group TTN condition, ($M = 93\%, \ SD = 0.0268$) in the late group TTI condition, and ($M = 96\%, \ SD = 0.0055$) in the late group TTN condition.

RTs

A repeated-measures ANOVA with condition and group as between-subject factors and block as a within-subjects factor showed that the interaction of block x condition was not significant, $F(1,56) = .765$, $MSE = 155$, $p = .386$. A main effect of block indicated that RTs increased significantly when
transferring from block 14 to 15 (early group) and block 19 to 20 (late group) $F(1,56) = 16.2, \text{MSE} = 3280, p < .001$. There was neither a main effect of group, $F(1,60) = .097, \text{MSE} = 564, p = .757$, nor a main effect of condition, $F(1,60) = 3.5, \text{MSE} = 20770, p = .064$. Importantly, the Block x Condition x Group was significant, $F(1,56) = 5.9, \text{MSE} = 1192, p = .018$ indicating that the increase in reaction time between conditions, was more pronounced in the early group compared to the late group. A post-hoc analysis of the early condition indicated that participants who transferred to previously irrelevant information experienced a significantly greater increase in reaction time than those who transferred to a random sequence, $t(29) = 1.95, p = .03$. Whereas in the late group, both conditions were equally effected by transfer $t(27) = -.19, p = .17$. Thus, a negative priming effect was found in the early condition and not the late condition. (See figure 3)

![Figure 3](image-url)
In summary, the results of Experiment 2 show that responding to a previously irrelevant second order sequence after 14 blocks of 100 trials produced a negative priming effect on SRT performance. The RT difference in transfer effect between the TTI and TTN conditions within the early group was 39.08 ms. This difference is in line with the RT difference between conditions in previous studies in which negative priming has been observed (Cock et al., 2002; Deroost et al., 2008). However, when participants transferred after 19 blocks of 100 trials, there was no negative priming effect. The same question from Experiment 1 now applies to the late group of experiment two: Does the absence of negative priming indicate participants haven’t learned anything, or that learning has been completed? Given that negative priming was observed in the early group which indicates that participants were in the process of learning the irrelevant sequence, we conclude that the absence of negative priming in the late group indicates that participants have completed learning of the irrelevant sequence, rather than not having learned anything. The notion that learning of the irrelevant sequence was likely completed is consistent with the findings of Shanks, Rowland, and Ranger (2005) who concluded that long exposure to sequence learning leads to the information becoming automatized and hence, less susceptible to disruption.

**General Discussion**

We conducted two experiments to investigate the degree of automaticity involved in irrelevant sequence learning. Using the negative priming effect, we compared learning of irrelevant sequences at different time points in the Serial Reaction Time (SRT) task. The negative priming effect occurs when SRT performance significantly decreases when participants respond to a sequence they were previously ignoring as compared to a novel or random sequence (Cock et al., 2002). Deroost et al. (2008) used this effect to provide evidence that participants can independently learn an irrelevant second order sequence, while simultaneously responding to a relevant sequence. However, because the explanation
of this finding remains unclear, we investigated the temporal onset of irrelevant sequence learning during the SRT task in two experiments.

Deroost et al. (2008) found negative priming after 12 blocks of ignoring a second order conditional sequence. In Experiment 1, we used the dual-sequence SRT paradigm from Deroost et al. (2008), but made the irrelevant sequence a less complex first order conditional (FOC) pattern. We choose to make the irrelevant sequence less complex, while keeping 12 blocks of learning because FOC learning takes less time than SOC learning. Previous studies have shown that when the information is relevant, participants can learn a first order sequence by 7 blocks of 80 trials (Cherry & Stadler, 1995; Dennis et al., 2006; Kelly et al, 2004). Therefore, we chose to measure the presence of negative priming in experiment 1 after 7 blocks of learning (early group) and after 12 blocks of learning (late group). If irrelevant sequence learning is automatic and begins as soon as relevant learning begins, participants in the early group should be done learning. The results of Experiment 1 showed that at both early and late transfer points, participants were not significantly disrupted when responding to the previously irrelevant sequence compared to responding to a random sequence. Thus, no negative priming was observed in either group. The absence of negative priming in both groups can be interpreted as participants not learning the irrelevant sequence, or that learning was completed. However, the results of Experiment 2 offer a clearer explanation of the observed effects. In Experiment 2, when responding to an irrelevant second order sequence, participants in the early group (14 blocks), and not the late group (19 blocks), were significantly more disrupted when responding to previously irrelevant information compared to responding to a novel sequence with equal complexity.

This presence of negative priming in the early group signifies that participants had obtained some knowledge of the irrelevant sequence after 14 blocks of learning. These results are consistent with Deroost et al. (2008) who showed the same effect after 12 blocks of similar learning. Therefore, we
suggest that the absence of negative priming after 19 blocks in Experiment 2 reflects the fact that the irrelevant sequence became completely learned, or at least learned enough for the disruption in performance usually caused by the negative priming effect to disappear. This notion offers support to the conclusion that the absence of negative priming in Experiment 1 is a result of the irrelevant sequence being completely learned, much like in the late group of Experiment 2.

Originally, we hypothesized that if irrelevant sequence learning is non-automatic, and is reliant on the release of attentional resources from learning the relevant sequence, then we should find a significant difference in the degree of negative priming when comparing an early transfer group to a late transfer group. This finding would indicate a temporal lag in the onset of irrelevant and relevant learning. Alternatively, if irrelevant sequence learning is automatic, then learning of both sequences should start concurrently and negative priming should not differ between the early and late groups. The results of Experiment 1 importantly show that learning of the irrelevant sequence was completed by 7 blocks of learning, which is in line with previous research showing participants can learn the same information when relevant (Cherry & Stadler, 1995; Dennis et al., 2006; Kelly et al, 2004). If learning of the irrelevant sequence in Experiment 1 started temporally distant from learning of the relevant sequence, it is likely that we would have observed negative priming in at least the early group. Therefore, we conclude that the onset of irrelevant sequence learning was concurrent with relevant sequence learning.

The current study provides insight into the findings of Deroost et al. (2008) by suggesting that irrelevant sequence learning is not based on the release of cognitive resources, but rather occurs concurrently with learning of relevant information. This conclusion supports Jimenez and Mendez (1999)’s notion that implicit sequence learning is automatic, as long as selective attention is directed towards the predictive dimension. Hence, as soon as learning of the relevant sequence begins, and
because the irrelevant sequence occurs within the same predictive dimension, both sequences are acquired automatically.

An alternate interpretation of the current results may be that the absence of negative priming in Experiment 1 is due to the fact that the relevant and irrelevant sequences were of different complexity. Although Keele et al. (2003) defined a dimension as “modality” and included spatial location as its own dimension, it may be the case that sequences with more complex second order information are learned in a different dimension than that of first order information, and thus, the irrelevant dimension of first order learning was never initiated. Consequently, a limitation of the current study is that we cannot firmly conclude whether or not the type of higher order information (i.e. first order or second order) within the sequences acts as a dimension. A future study would be useful to investigate this question by comparing negative priming of first order relevant and first order irrelevant sequences, with that of a second order relevant sequence and a first order irrelevant sequence as in the current study. Another limitation of the current study is that there were only two groups in which to access the temporal onset of irrelevant learning. That is, by concluding that learning had finished after 7 blocks in the early group of Experiment 1, we cannot firmly comment on what is happening in the preceding blocks. A future study should expound on the learning curve of irrelevant sequence learning by including transfer groups in earlier blocks to more accurately assess when learning begins.

In conclusion, a growing numbers of studies seem to be homing in on the idea of implicit sequence learning being a highly automatic process, with the constraint that selective attention must be devoted to the to-be-learned information (Perruchet & Gallego, 1997; Cleeremans & Jimenez, 1998; Frensch, 1998; Jimenez & Mendez, 1999; Coomans et al., 2012). The ability to detect regularities in an environment is a highly adaptive trait for an organism, as this allows for the prediction of future outcomes and the ability to adjust behavior accordingly. It seems logical that somewhere along the path
of primate evolution, as more conscious processes developed such as executive functioning; detecting regularities developed as an automatic process insofar as not to impede on cognitive resources needed for other conscious mechanisms. However, with the wide range of perceptual information we receive at any given moment, it would not be adaptive for implicit mechanisms to be so automatic as to associate every piece of information together. Therefore, it might follow that selective attention remains an important filter within this automatic process that associates only the information in a predictive dimension that is somehow delegated as meaningful.

Given the current findings, we hope to tie together many pieces of literature that support the idea of implicit learning as a highly automatic process, and offer an explanation to the findings of Deroost et al. (2008) that irrelevant sequence learning begins early and around the same time as relevant sequence learning. Showing that one can simultaneously learn highly complex sequences, and it being a matter of implicit mechanisms, is a truly remarkable accomplishment of the human brain. Further research might take a comparative approach in assessing implicit sequence learning abilities between species, as this avenue of research may offer a unique perspective into when and why automatic implicit learning developed.
On the automaticity of irrelevant sequence learning

References


Appendix

Questionnaire form:

1) Did you adopt any special strategy in performing the task?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

2) Did the stimuli appear randomly or predictably?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

3) Can you tell me something about the way they appeared?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

4) Did you try to take advantage of this repeating regularity to anticipate what event was coming next? Did this help?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

5) Were stimuli in a single repeating sequence or were some positions more probable?

________________________________________________________________________
6) Did the sequence appear continuously, or did it come and go?

**Rubric for scoring:**

Q1:

Mention anything about noticing a pattern = 1, otherwise 0.

Q2:

Random = 0, predictable = 1

Q3:

Obvious information about design = 0, some mention of a pattern or incorrect description = 1, parts of pattern correctly identified = 2

Q4:

Yes = 1, No = 0

Q5:

Single repeating sequence = 1, some positions more probable = 0

Q6:

Continuous = 1, Come and go = 0