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IMPLICIT AND SEQUENTIAL LEARNING
IN A MOTOR SEQUENCE TASK

KAITLYN PATRICIA MCCAFFREY
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Reviewed and approved* by the following:

Carol Miller
Associate Professor
Thesis Supervisor
Honors Adviser

Krista Wilkinson
Professor
Second Reader

* Signatures are on file in the Schreyer Honors College

ABSTRACT

While current research suggests that procedural and implicit learning are present in overall language learning, there is little known about their presence in a motor sequence task. This current study aimed to find a presence of procedural/implicit learning in a gesture sequence task conducted on children with and without language impairments. To ensure the experiment was designed effectively, the task was also performed by five adults. The gesture sequence task was presented on a computer screen and included four hand shapes. Participants were asked to imitate the hand shapes as quickly and as accurately as possible. The task contained 200 hand shapes broken up into four phases: 50 random trials, two sets of 50 sequential trials, and a final 50 random trials. Each participant's performance was recorded so that completion times could be calculated. Completion times were calculated in sets of ten hand shapes. A shorter completion time for the sequential trials than the random trials suggests a presence of procedural and implicit learning. A majority of the adult participants had decreased completion times by the 2^{nd} phase of the sequential phase followed by an increase in completion times for the final random phase. However, when the children performed the task, mixed results were found. Only one of the five children showed a pattern of completion times that was consistent with procedural and implicit learning. These mixed results may be due to fatigue, attention span, or the design of the experiment. Future studies will need to alter the task by increasing the number of trials, removing the requirement to replace the hand after each gesture, or removing the break during the sequential phase of the task. These alterations may decrease the variability of results.

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INTRODUCTION

Language and Working Memory Abilities

This current study aims to investigate procedural and sequential learning in a gesture sequence task of children with and without language impairments. However, before a connection between sequential learning and gestural abilities can be made, a strong understanding of the connection between language and working memory is needed. Comprehension of this connection is vital to understand working memory's role in the procedural and sequential learning that may be present in language.

A popular theory of language abilities is that deficits in working memory cause impairments of language. According to Baddeley (2003), working memory is necessary for various "complex cognitive activities" which include verbal and acoustical information (Baddeley, 2003). To investigate this theory, many researchers have investigated working memory skills in children that show evidence of language disorders.

Leonard, Ellis, Weismer, Miller, Francis, Tomblin, and Kail (2007) compared abilities in working memory tasks of fourteen-year- old adolescents diagnosed with language impairments to their typically developing classmates. When the language composite scores of the two groups of students were compared, working memory was found to be the most prominent factor contributing to the differences in language scores. These results suggest, but do not confirm, that working memory plays a major role in language abilities (Leonard et al., 2007).

Just and Carpenter (1992) stated that the reason working memory plays a key role in language is that humans use working memory to process and store the sequences of sounds and symbols involved in language. In Just and Carpenter's theory, lack of working memory storage diminishes a person's ability to store and process complex language. To determine working memory as it relates to language skills, Daneman and Carpenter (1980) designed a "sentence-span task." In this task, a list of sentences is read to each participant. After all sentences have been read, participants are asked to repeat the last word of each sentence. A significant number of incorrect answers will be recorded if working memory is impaired. The sentence-span task was adapted to be used on children by Gaulin and Campbell (1994). This adapted task is called the Competing Language Processing Task (CLPT) and was used in the current study.

Specific Language Impairment

Children diagnosed with specific language impairment (SLI) are a population that is typically used to investigate working memory and other components of language ability. According to Evans and Saffran (2009), children with SLI have severe difficulty acquiring language despite the absence of any cognitive, hearing or neurological problems. The isolated deficit of language in SLI makes these children good candidates to study working memory and its effects on language abilities. This is because all other deficits, such as hearing or cognitive problems, can be ruled out as problems affecting their language abilities.

The theory of working memory playing a role in language abilities prompted Baddeley (2003) to test verbal working memory in children with SLI. Baddeley used the

Goldman, Fristoe, Woodcock test of verbal working memory to compare children with SLI to their typical peers. The children with SLI scored significantly below their typical peers on verbal working memory. This study supports the claim of working memory playing a significant role in language ability.

History of SLI and FOXP2 Gene

Individuals with SLI have also been investigated to support the claim that in addition to working memory, underlying deficits in motor planning and sequencing also cause linguistic and grammatical impairments. However, before discussing motor sequencing in SLI, a history of the first identified gene link of SLI in a family is necessary.

The FOXP2 gene was discovered in 2001 by Lai, Fisher, Hurst, Vargha-Khadem, and Monaco (2001) as the gene responsible for a severe speech disorder. Evidence for this discovery was found in a large family whose initials' are KE. The KE family consists of three generations in which an inherited speech and language difficulties are evident. Half of the family members have SLI which is characterized by a severe expressive language disorder and a severe verbal dyspraxia in the absence of any other developmental disorder. The affected members of the KE family exhibit problems with expression and grammar as well as difficulty with mouth movements and coordination which affect their ability to speak. It was through extensive research on the KE family that FOXP2 was identified as the gene for their phenotypic profile. The breakthrough discovery of the KE family has motivated other researchers to further explore the FOXP2 gene as a cause of language disorders (Lai et al., 2001).

Affected members of the KE family exhibit developmental verbal dyspraxia and issues with linguistic and grammatical processing. The KE family has thirty-seven members and fifteen of them have a mutation of FOXP2 that causes them to have a severe SLI (Tomblin, O'Brien, Shriberg, Williams, Patil, Bjork, Anderson & Ballard, 2009).

Tomblin et al. (2009), discovered a mother and daughter who also exhibit similar language and cognitive profiles to the KE family. These results were found through a series of standardized tests of intelligence, receptive and expressive vocabulary, sentence use and a spontaneous language sample. The mother and daughter show evidence of a mutation in FOXP2 which further supports the theory that FOXP2 influences language. However, it is still unclear whether FOXP2 abnormalities are affecting motor skill abilities or procedural learning which in turn cause a language difficulty.

Lai et al. also discovered a person, unrelated to the KE family, which supports FOXP2's involvement in SLIs. The patient, CS, has a speech and language disorder that is extremely similar to that of the KE family (Lai et al., 2001). Both CS and affected members of the KE family have extreme difficulty with expressive and receptive language, and a mutation in the FOXP2 gene. Results of this study give more evidence to the widely suggested belief that FOXP2 plays a crucial role in language and speech development.

Belton, Salmond, Watkins, Vargha-Khadem & Gadian (2003) took FOXP2 research one step further to find how the brain differs in people that exhibit the mutation of the FOXP2 gene. The study compared areas of grey matter density in the MRI scans of the affected and unaffected KE family members. The main finding was that the affected family members have reduced grey matter density especially in the left caudate nucleus. This nucleus is located in the basal ganglia, and plays an important role in learning and memory. The caudate nucleus also contributes to motor control and has been suggested to affect language comprehension and articulation. These results further suggest that FOXP2 is associated with abnormalities in the motor and language regions of the brain (Belton et al., 2003).

Lai and her colleagues agree with the hypothesis that impairments in the motor and language regions of the brain may be the underlying cause of the FOXP2-related speech and language disorder (Lai et al., 2003). A study, conducted by Lai et al, using brains from mice, found that the foxp2 gene expression was not limited to one single part of the brain. The expression was also found in various parts of the brain: the cerebellum, thalamus, and medulla. More importantly, the expression is found in the neural circuits that are responsible for motor control. These circuits include the: basal ganglia, thalamus, inferior olives and the cerebellum. This information was also found human brains after dissection (Lai et al., 2003). These results suggest a link between motor planning and language ability in human brains.

The collection of results and findings surrounding FOXP2 gene suggest that underlying deficits in motor planning and sequencing are related to the linguistic and grammatical impairments seen in the KE family. However, more research needs to be conducted to rule out the chance that the motor and cognitive problems arise simultaneously with the language impairments. This current study investigates the abilities on a gestural sequence task of children with and without language impairments.

Children will first be administered basic language assessments followed by a gesture sequence task. The data from both the language and motor assessments will be reviewed to further examine the relationship of motor and procedural learning abilities and the way they relate to broader language and learning abilities.

Procedural Learning

Procedural learning is a type of implicit memory learning which relates to the ability to practice a procedure to create cognitive or motor skills. The key aspect of procedural learning is that subjects should increase speed and accuracy as the amount of exposure to the procedure is increased (Cohen and Squire, 1980). Tomblin, Arnold, & Zhang (2007) found that adolescents with SLI exhibit slower development of pattern learning, also known as procedural learning. This was found by comparing serial reaction time (SRT) in children with SLI compared to children without SLI. A SRT task was created using random sequences as well as predictable sequences. A total of 400 stimuli were presented to the children in four different phases. The first phase consisted of 100 stimuli in a random order. The second and third phases consisted of 100 stimuli each. The stimuli in these two phases were presented in a sequence of 10 stimuli long (1-3-2-4-4-2-3-4-2-4). The fourth phase was another 100 stimuli in a random order. The serial reaction time during the two sequential phases was slower for children with SLI compared to children without SLI. There was no difference between the two groups of children during the random phases. The fact that there was a difference in children with SLI when there was a procedure to be learned, suggests that a procedural learning deficit may also be present in children with SLI. This deficit in procedural learning of children with SLI suggests that procedural learning may affect language abilities. The Tomblin et al (2007) research design was adapted for the current gestural sequence study.

Implicit and Statistical Learning

Implicit learning refers to the ability to acquire language, cognitive, motor, etc. skills without undivided attention and without the specific intent to focus and learn a task (Perrruchet, 2006). Statistical learning, with regard to language, refers to the ability to decipher statistical relationships to acquire language. Emberson, Conway, and Christiansen (2011) combined the two into implicit statistical learning which they found to be affected by the rate of presentation. It was found that if the sequence was presented at a fast rate, the implicit statistical learning rate was better for auditory learning than visual. This shows that implicit and statistical learning have differences in both the auditory and visual fields which is caused by rate of the sequence (Emberson, 2011).

Saffran, Aslin, and Newport (1996) found that 8 month old infants were able to identify word boundaries in an artificial language based on the statistical sequence they learned from being exposed to a 2 minute stream of an artificial language (Saffran, 1996). In Saffran's study, 24 8 month year olds from English speaking environments were exposed to 2 minutes of nonsense syllables. An example of the nonsense stream is "bidakupadotigolabubidak." It can be concluded that infants were able to decode the word boundaries through use of statistical learning (Saffran, 1996).

The difference between implicit and statistical learning is that implicit learning utilizes "chunking", and statistical learning uses computation of statistical probabilities. The idea of "chunking" or breaking apart into parts to learn a sequence can be applied to serial reaction time tasks. The idea of computing statistical probabilities can be applied to serial reaction time (SRT) tasks because subjects could statistically compute the probability that one stimulus would follow another. Both implicit and statistical learning were used to hypothesize the increase in SRT during the procedural phases of this current study.

Motor Sequence Learning

Motor sequence learning in adults has been broken down into three phases: a first session which has rapid improvement in performance, a second phase known as consolidation, and a third phase which is when improvement in performance levels off. Unfortunately, little is known about motor sequence learning in children. It is not clear if they learning motor sequencing in the same fashion as adults (Savion-Lemieux, Bailey, & Penhune, 2009). Ghilardi, Moisello, Silvestri, Chez, and Krakauer (2009) found that the two basic components of motor sequence learning, regardless of children or adults, are the ability to acquire the sequence of stimuli, and the ability to perform the motor sequence task quickly and accurately (Ghilardi et al, 2009).

Motor skill learning is an area of weakness for children with language impairment. A study conducted by Iverson and Braddock (2011), found that compared to their peers, children with language impairments perform worse on fine and gross motor skill tasks (Iverson & Braddock, 2011). More precisely children with SLI show deficits in tasks that require coordinated movement. Hill (2001) found that children with SLI score significantly worse than typically developing peers in a gesture sequence imitation task. It was found that poor limb motor ability was a common occurrence with SLI.

(Hill, 2001). This link between language and motor skill issues in children with SLI may be caused by their weakness in imitation. This is because imitation is the most common way for children to acquire language or motor skills (Marton, 2009). This current study aims to link procedural/statistical learning to abilities of children with or without language impairments on an imitation gestural sequence task.

Gesture Skills

In 1998 Hill conducted a study to find how well children with SLI can produce non-symbolic gestures compared to their peers. This task was not timed, and the children with SLI did not differ from their typically developing peers. However, when children were asked to participate in a coordinated sequence of gestures, Hill (2001) found that children with SLI performed worse than children without SLI. It was only when the children were required to imitate a gesture sequence that a difference was exhibited.

Hill (2001) conducted a review of research on gestural and language abilities in children with general language impairments (aside from SLI) and found evidence suggesting that there is a direct correlation between language composite scores and gesture production. There was also a significant relation between fine motor scores and gesture production.

As reviewed by Hill in 2001, numerous research studies have evaluated the production of symbolic and non-symbolic gestures in children with and without SLI. Studies confirmed that children with SLI struggle with producing symbolic gestures compared to their typically developing peers. However, mixed results have been found in terms of non-symbolic gestures. Further research is needed on whether there is a difference in production of non-symbolic and symbolic gestures exists between children with and without SLI (Hill, 2001).

The combination of current research studies of children with SLI suggests that there is a common underlying cause for language, motor, and gestural deficits in these children. Future research should be conducted to find which learning deficits in children with SLI causes them to perform worse on gesture sequence tasks. This current study aims to find out if the link between language composite scores and gesture production is a procedural learning and implicit learning deficit. A link will open the door to further investigation in this area (Hill, 2001).

Research Questions

This current study aims to link deficits in procedural and implicit learning to both language and gestural sequence imitation abilities in children with and without language impairments. Due to the limitations of this study, the results cannot be specifically applied to children with SLI or genetic disruption of the FOXP2 gene. However, the motor skill and language deficits of children with SLI were used to hypothesize that there may be broader learning mechanisms that affect language and the ability to imitate a sequence of gestures. By testing children with and without low language performance, this study will aim to link broad procedural learning and implicit learning abilities to abilities on a gestural sequence task.

It is hypothesized that if a child exhibits procedural/implicit learning on the gestural sequence task, there will be a shorter completion time for the sequential trials than the random trials. A lack of procedural/implicit learning may be caused by underlying language deficits. It is expected that children who score average, or above average on standardized tests of language will be able to display evidence of implicit learning in the gesture task. Those children scoring below average on language tests may not exhibit a shorter completion time for the sequential trials due to an underlying deficit in procedural/implicit learning.

METHODS

Participants

Five children were recruited from Penn State's Language and Literacy Research Initiative (LLRI) which recruits school age children with and without language disorders. LLRI runs preliminary language and literacy tests on these children and enters the results in a database. These children can be contacted for future research experiments such as this gestural sequence task. The children used for this research had ages ranging from seven to twelve.   Four of the children were female and one was male.

Five adults were also recruited for the gestural sequence task. All five adults were undergraduate students at Penn State University. None of the adults had any language, cognitive, or motor issues. This was done to ensure the experiment would run smoothly on participants who were not expected to have any difficulty or conflicting deficits.

Language Assessments

The LLRI database was used to review each child's Clinical Evaluation of Language Fundamentals—4 (CELF-4) score. The Clinical Evaluation of Language

Fundamentals- Preschool—2 was used for the youngest participant. The CELF-P2 is used for children ages 3-6 years old and is designed similarly to the CELF-4. The core language standard score and an expressive language index standard score were listed for each child. The core language standard score is typically used to make decisions of whether or not a child has a language disorder. The expressive language index standard score is a comprehensive assessment of the child's overall expressive language abilities (Pearson, 2008). The scores for each child participant are listed in Table 1 and Table 2 below.

Table 1. Overall speed, average completion times for each phase, CELF-4 Core Language and Expressive Language scores, and WASI scores

ID#	Overall Speed (min)	1st Random Phase Avg. (sec)	100 Seq. Avg. (sec)	2nd Random Phase Avg. (sec)	Celf-4 Core Language Score	CELF-4 ELI Expressive Language	WASI
BAA 76	10.8	42.6	30.5	25.8	109	103	104
BAA77	10	27.4	27.4	27	77	77	91
AAA31	8	30.8	21.8	21.6	83	83	88

Table 2. Overall speed, average completion times for each phase, CELF-P2 Core Language and Expressive Language scores, and Leiter-R scores

ID#	Overall Speed (min)	1st Random Phase Avg. (sec)	100 Seq. Avg. (sec)	2nd Random Phase Avg. (sec)	Celf-P2 Core Language Score	CELF-P2 ELI Expressive Language	Leiter-R
BAA01	6.25	23.6	17.7	16.2	106	81	129
BAA03	7.6	27	22.5	19	112	79	103

Table 1 and Table 2 present the overall time and average speed for each of the four phases of the gesture sequence task. In addition to the gesture task times, language assessment scores from the CELF-4 and CELF-P2 are also presented. Lastly, the cognition assessment scores from the WASI and Leiter-R are listed.

Cognitive Assessments

In addition to language assessments, the WASI Performance IQ scores were also recorded and presented in Table 1. The WASI Performance IQ tests processing speed as well as perceptual organization. The Leiter-R was used instead of the WASI for the youngest participant. The Leiter-R is similar to the WASI assessment, but is specifically designed for younger children. The scores for the Leiter-R are presented in Table 2. The overall cognitive background of the children is necessary to rule out any conflicting deficits that may hinder their ability on this gestural task.

Gestural Sequence Task

Stimuli

The stimuli were black and white pictures of four basic hand shapes. Two sets of stimuli were used: one set for right- handed participants and the other set for the left-handed. To ensure that the pictures were clear, a digital photo was taken of each hand shape. These photos were then printed out and traced using a black marker. The traced photos were then scanned and uploaded onto a computer. The four hand shapes used were: fist, an open palm face down, an open palm facing the participant's body, and a c-shaped hand face down (see Figure 1.).

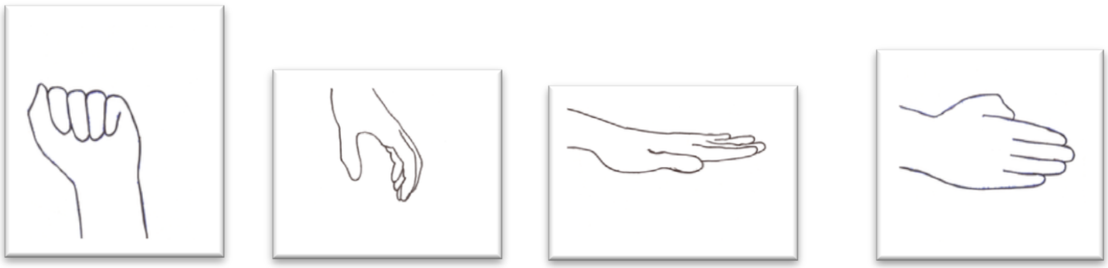

Figure 1. Right Hand Shapes: the four hand shapes presented to right-handed participants

There were 200 stimuli total presented to the children in a PowerPoint presentation. The first 50 stimuli were in a random order. This was followed by 100 stimuli in a sequence. Each hand shape was assigned a number one through four and arranged in a sequence. The sequence (1-3-2-4-4-2-3-4-2-4) was repeated 10 times. The 100 stimuli in sequential order were followed by another 50 stimuli in random order. Reaction times were calculated for each set of 10 stimuli.

Procedure

The experiment was designed in Microsoft PowerPoint and was presented on a Dell computer. Undergraduate research assistants were trained to properly deliver the experiment. A video camera was used to record the participants. The instructions given were: "You are going to see different hand shapes. We want you to imitate them as quickly and accurately as possible. After imitating each shape, place your hand back on the desk." The participants were then shown the four hand shapes and were given immediate feedback on how to correctly imitate the shape. After learning the four hand shapes, they were given a practice trial of nine stimuli. This enabled them to learn how to quickly imitate the hand shape and to return their hand back to resting position. As soon as their hand was placed on the table, the experimenter clicked to present a new hand shape. Feedback was given during this practice trial. The experiment then proceeded to the sets of 50 random, 100 sequential and 50 random. After each block of fifty trials they were presented with a short break which never exceeded thirty seconds. Each break slide had a motivating sentence and had a pie chart showing them how many trials they had completed. For example, the first break slide had a pie chart that had one third of it filled in. Examples of motivating sentences used are: "keep up the good work" and "you are almost there."

RESULTS

Analyzing the Data

Data was collected and participant completion times were measured by reviewing the video tape of each participant. The time stamp on the video camera was used to measure the length of time for each phase of the task. Completion times were examined in four groups of fifty trials. These groups were composed of: first fifty random trials, two groups of fifty sequential trials, and the final fifty random trials. To ensure that the analysis of participant data was precise, each of the four groups of fifty was broken down into sets of ten gestures. For example, the first group of fifty random was broken down into five sets of ten gestures. The completion times were used to determine procedural and implicit learning. A learner that exhibits sequential learning is expected to complete the sequential trials faster than the random trials.

Adult Participants

The follow figures depict the results from the adult participants. The experiment was administered on adults to ensure the task would run smoothly. The data was collected to verify whether or not implicit learning is exhibited by participants who are expected to show learning during the task.

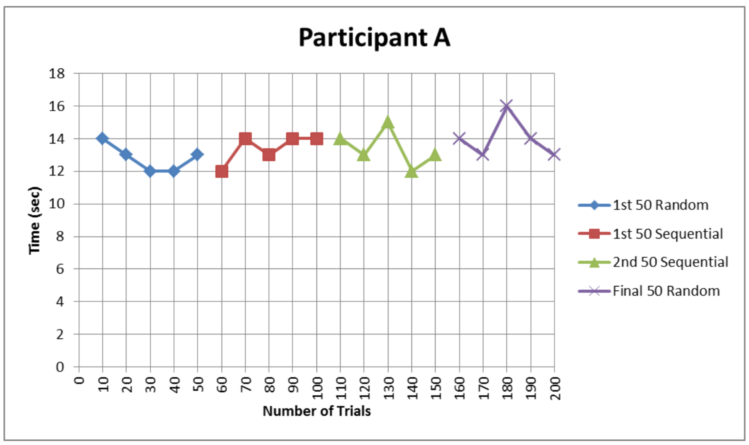

Figure 2. Gesture Sequence Task: Completion times for Participant A

Figure 2 shows the completion times for the adult Participant A. The data is an example of the implicit learning that should occur during this gesture sequence task. Implicit learning is specifically seen during the end of the sequential phases when the completion times significantly decrease. This is followed by an increase in completion times for the final phase of random trials.

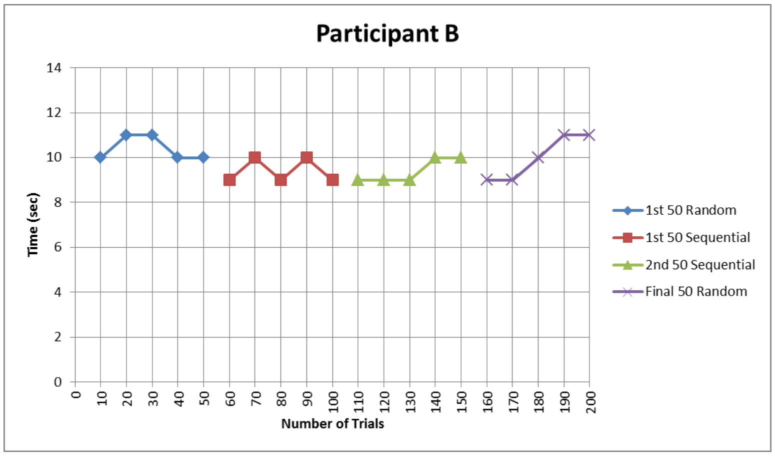

Figure 3. Gesture Sequence Task: Completion times for Participant B

As seen in Figure 3, participant B exhibited less conclusive results for implicit and sequential learning. There is a drop in time during the sequential phase, but towards the end of the sequential phase there is an unexpected increase in time. This is followed by a drop of completion time during the beginning of the final random phase. This data does not support the theory of implicit learning during the gesture sequence task.

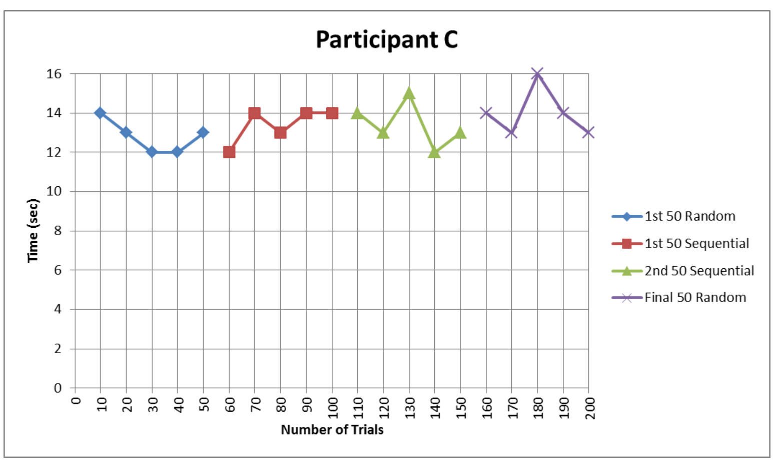

Figure 4. Gesture Sequence Task: Completion times for Participant C

Figure 4 shows implicit learning occurring during the gesture sequence task. This is evident by a decrease in time during the end of the sequential phase. This is followed by an increase in completion time during the beginning of the final random phase.

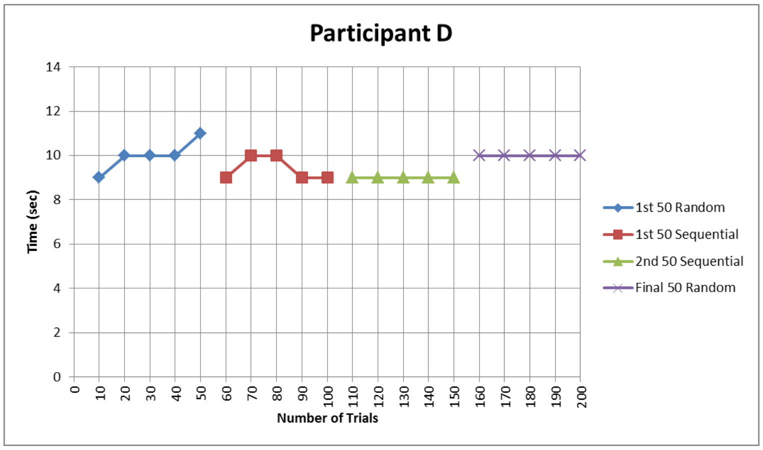

Figure 5. Gesture Sequence Task: Completion times for Participant D

Figure 5 shows strong evidence for implicit learning occurring during the gesture sequence task. Participant D decreases time during the second half of the sequential phase and this decrease in completion time remains steady. This is followed by an increase during the final random phase.

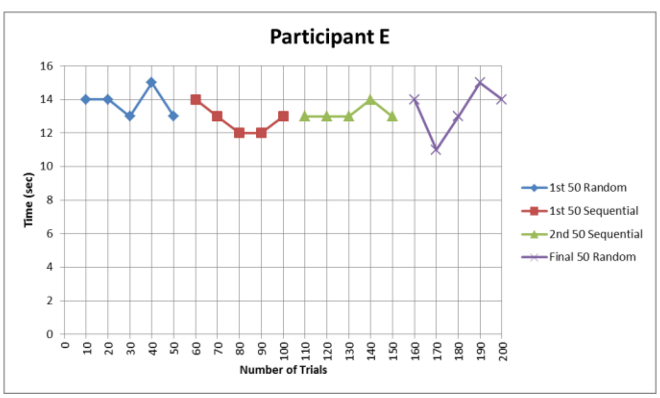

Figure 6. Gesture Sequence Task: Completion times for Participant E

Figure 6 does not strongly support implicit learning during the gesture sequence task. The completion time during the sequential phase is less than the first random phase, but the times during the sequential phase are very inconsistent. There is also a decrease in time during the beginning of the final random phase.

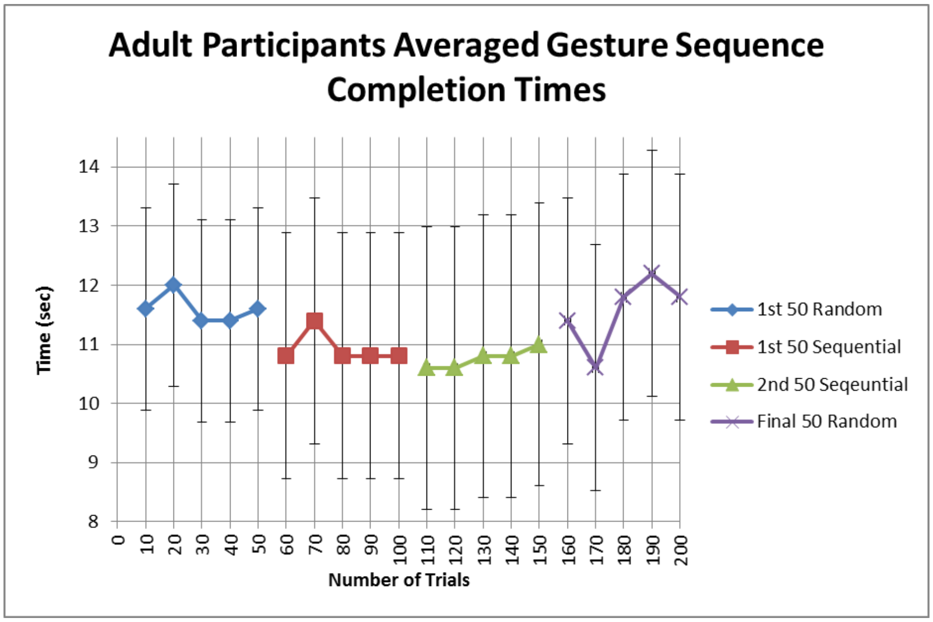

Figure 7. Averaged completion times for all of the adult participants. Error bars indicate standard deviations.

Figure 7 shows the averages completion times for all the adult participants in the gesture sequence task. When the completion times are averaged, a clear indication of implicit learning during the gesture task is observed. There is an observable decrease in time from the first random phase compared to the two sequential phases. There is also a noticeable decrease in time during the final 50 sequential trials. This is followed by a an increase in time in the beginning of the final random phase.

Child Participants

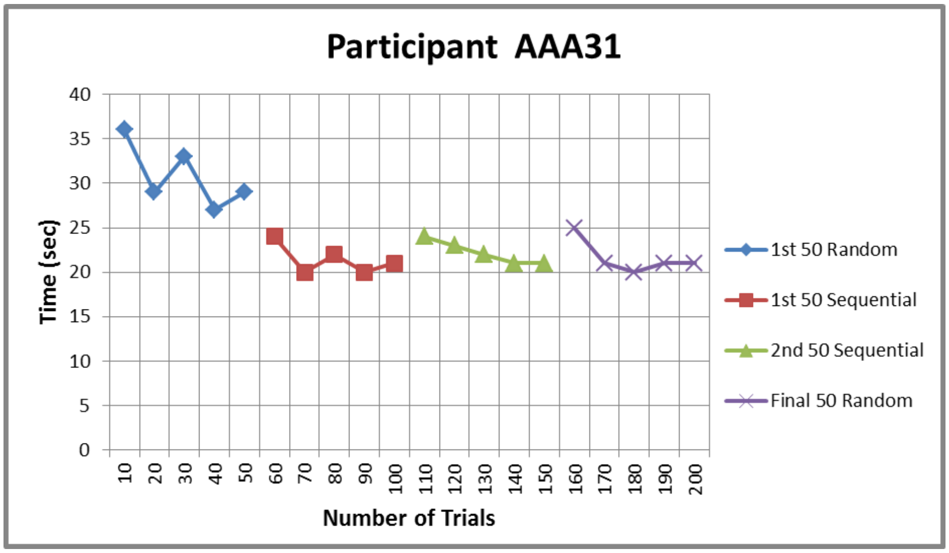

Figure 8. Gesture Sequence Task: Completion times for participant AAA31

Figure 8 shows that participant AAA31 exhibits procedural learning in the gesture sequence task. During the first random phase, there is an inconsistent decrease in time. Unlike the random phase, the two sequential phases have a steady and consistent decrease in completion times. This is followed by an increase in the completion time for the first 10 trials of the final random phase. However, the final 40 trials of the random phase are similar to the completion times of the two sequential phases.

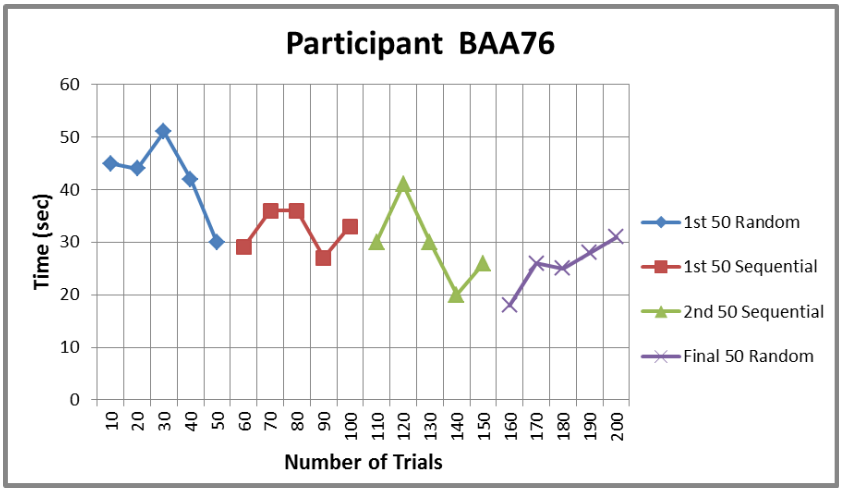

Figure 9. Gesture Sequence Task: Completion times for participant BAA76

In Figure 9, the data shows that participant BAA76 did not appear to demonstrate procedural learning during the sequential phases. The participant exhibited a significant decrease in completion time by the end of the 1st random phase which is not expected. Also throughout the two sequential phases, the participant did not appear to decrease their completion time as expected, but rather had sharp increases in time. At the end of the second sequential phase there is a decrease in completion time, but this decrease is also seen in the beginning of the final random phase. The lack of evidence for sequential and procedural learning may be due to fatigue or lack of motivation of the participant or by unrelated factors caused by the design of the experiment.

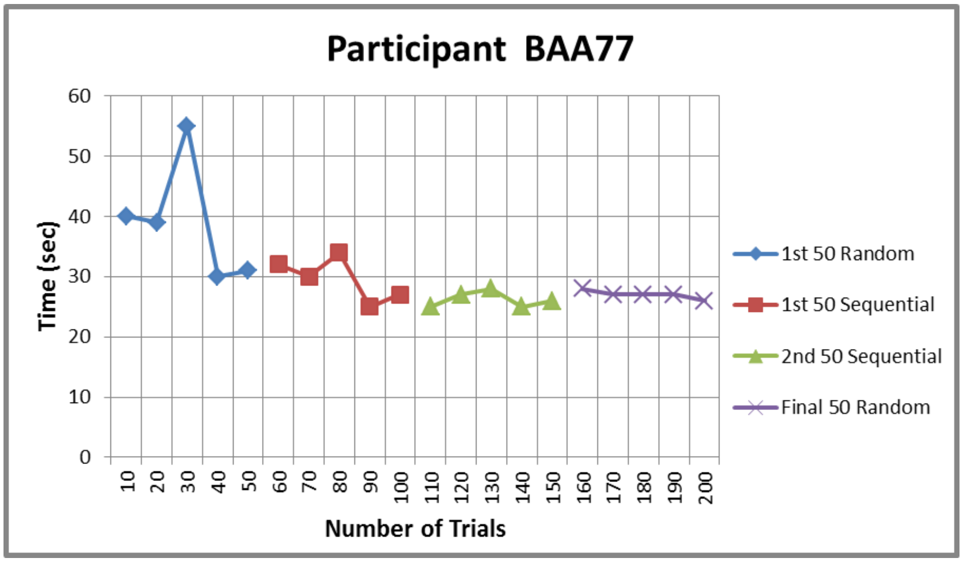

Figure 10. Gesture Sequence Task: Completion times for Participant BAA 77

Figure 10 does not show significant evidence for implicit learning in the gesture task. Although there was a decrease in time during the sequential phase, this decrease in time remains steady through the final random phase. If implicit learning did occur, it is expected that the completion time would increase during the final random phase.

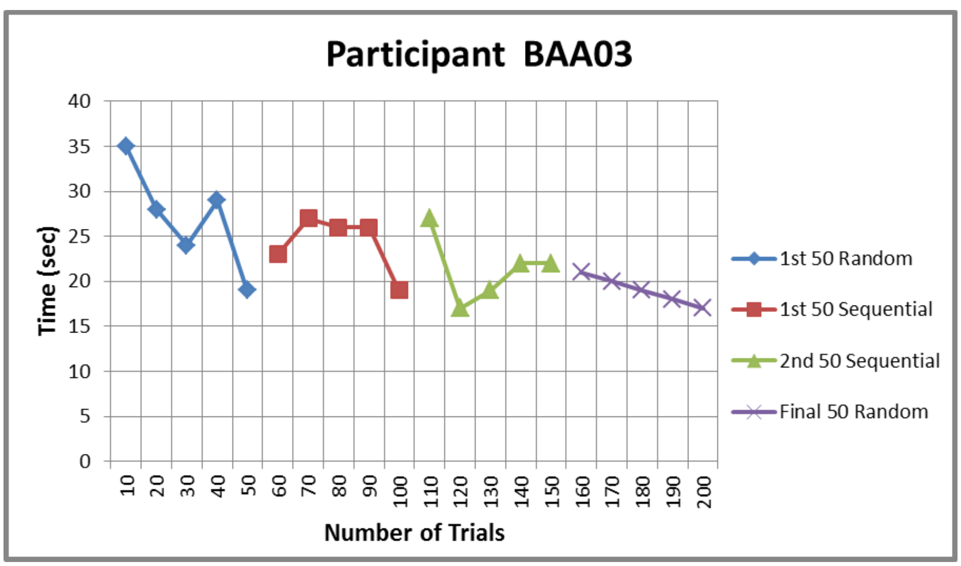

Figure 11. Gesture Sequence Task: Completion times for Participant BAA03

Figure 11 also does not show evidence of implicit or procedural learning occurring. The completion times are variable during the sequential phase, and a steady decrease in completion time does not occur. Also, there is a steady decrease in time during the final random phase which is not expected to occur. The data shows that the participant did not learn the sequence during the gesture task.

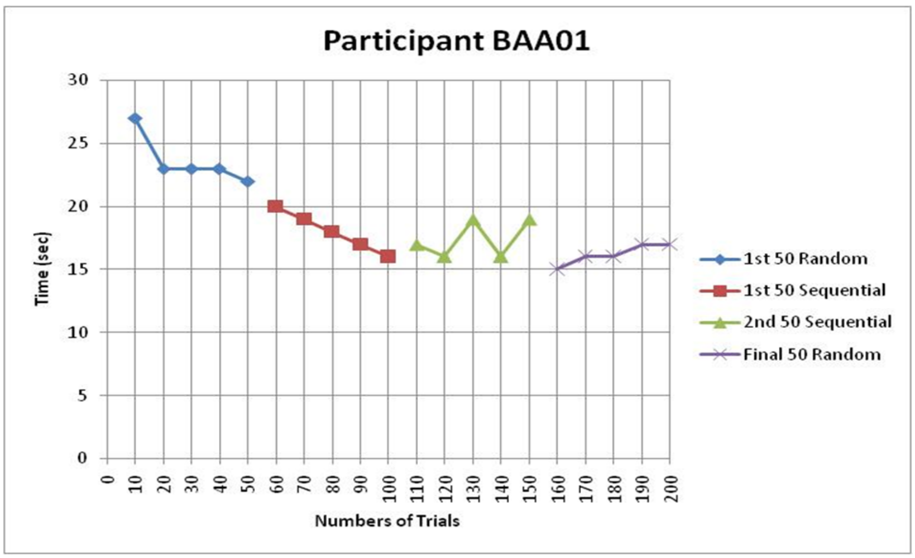

Figure 12. Gesture Sequence Task: Completion times for Participant BAA01

Figure 12 does not show a clear indication of implicit learning. Although the child gets progressively faster in the first half of the sequence, the completion time then rises towards the end of the sequence. The final random phase is also significantly faster than the sequential phase.

Results of Implicit Learning and Language/Cognition Assessments

The results of implicit learning and language/cognition do not show a definitive relationship between the two. Given that participant AAA31 was the only child to show evidence of implicit/sequential learning, it would be expected that they would have normal language and cognition scores. However, the data from Table 1 shows that AAA31 had the lowest CELF-4 subtest scores and second lowest Core Language Score and Expressive Language Score. AAA31 received a Core Language Score in the 14th percentile which suggests a language deficit.

In addition to AAA31, it's also interesting to consider the children that did not show evidence of implicit learning. Participants BAA 76 and BAA 03 both had high Core Language scores but did not show evidence of learning during the gesture task. Participant BAA 76 had a Core language score of 112 (73rd percentile) and BAA 03 had a Core Language score of 112 (79th percentile).

Furthermore, variable results in the performance IQ tests of the WASI and Leiter-R were also observed. BAA 76 had a performance IQ of 104 which is above average and expected since learning was observed during the gesture task. Participant AAA31 had the lowest performance IQ but was the only child to show evidence of learning. Also, BAA 03 received a score of 103 which is above average on the Leiter-R assessment. Much like the language scores, the cognitive scores show a great bit of variability and a definitive relationship cannot be formed.

DISCUSSION

Gesture Sequence Task Completion Times

This current study investigated the presence of implicit and sequential learning in gesture sequence task. Implicit learning was hypothesized to cause a decrease in completion times for the sequential phases compared to the random phases. In order to effectively evaluate the results, the gesture sequence task was broken up into sets of 10 gestures. As depicted in the individual and averaged graphs, implicit and sequential learning was observed in a majority of the adult participants. However, participant AAA31 was the only child participant to show significant evidence of implicit learning. This was indicated by a decrease in completion time for the sequential phase followed by an increase in time for the final random phase. The other four child participants had varied results and did not show evidence for learning.

Factors Contributing to Variable Results

The inconclusive results of this study only partially support the theory of implicit and sequential learning in a gesture sequence task. The mixed results may be due to factors such as fatigue, distractions, or participants developing a rhythmic pattern of response. These factors may have been more prominent for the child participants compared to adults due to their age, lack of motivation, or smaller attention spans.

Fatigue may have been a strong factor because of the physical demands that are required by the task. Participants were asked to lift up their arm, form a specified hand gesture, and then replace their hand on the table. This task may have been physically demanded for the participants that took a significant time to complete it. As seen in Table 1, some participants took up to ten minutes to complete the gesture task. The child may have experienced physical fatigue or lack of concentration during the length of time it took to complete.

Distractions in the room may have been another factor for the child participants. Many child participants were observed peering around the room or talking to the researcher that sat next to them during the task. The researcher tried their best to refocus the child, but it still affected completion times. Also, sometimes children failed to remember to put their hand back down on the table after completing a hand gesture. The children seemed to have to concentrate on to remember to replace their palm on the desk. This step in the task may have impeded their ability to learn the sequence.

Language and Cognitive Factors

When comparing gesture sequence completion times to overall language and cognition scores, there does not seem to be a relationship between to the two. These mixed results make it impossible to conclude if there is a clear relationship between language/cognitive abilities and implicit learning in a gesture sequence task. There may be factors within the design of the gesture sequence that may have caused these mixed results. Future research should consider alterations to the design of the task to eliminate any outside factors.

Alterations of the Gesture Sequence Task

Alterations of the original design of the gesture sequence task may be needed to eliminate mixed results in the future. Three possible changes to be implemented are: eliminating the break during the sequential phase, deleting the instruction to place the hand on the table between each gesture, and increasing the number of trials. Each of these changes individually or a combination of all three may yield more positive results for this study.

The rationale for removing the break in the middle of the sequence is to ensure that the participant is having the proper amount of continuous repetition to learn the sequence. Many of the child participants took longer than normal breaks and had conversations during the break. They expressed concerns of the task being tiring and not wanting to continue. This break allowed them to become discouraged and distracted at the very time they were expected to exhibit a decrease in completion time. Removing this break may allow the implicit learning that is expected to occur.

Removing the instruction to place one's hand on the table after each gesture may also have a positive effect. This was originally included in the instructions to signal the researcher to advance to the next gesture. However, it may have made the task more difficult for children to complete. There was numerous times in which the children and a few adults forgot to replace their hand on the desk. This resulted in them pausing with their hand in the air which increased completion times. Removing this instruction will reduce the cognitive load and increase the accuracy of completion times.

The last alteration to the task may be to increase the number of trials. Some of the child participants may not have learned the gesture sequence because there were not enough trials to allow them to learn it. If the number of trials is increased, it may be necessary to increase the number of breaks. The child participants will need enough breaks to ensure fatigue does not interfere. However, new breaks must not be inserted during the sequential phase to ensure they will not interfere with implicit learning.

Future Research

Although this current study found mixed results, further research needs to be conducted to investigate the role of implicit and sequential learning in a gesture sequence task. The alterations of the gesture sequence task discussed above may play a key role in future research. An increase sample size of both children and adults will also enable the results to be properly interpreted. Future research should aim to correlate gesture sequence task abilities to the language and cognitive abilities in children.

Alterations to the task will eliminate outside factors that impede participants' ability to exhibit implicit and sequential learning during the gesture sequence task. It is expected that children without low language performance will utilize implicit and sequential learning to decrease their completion times during the sequential phase of the task. If children with low language performance are unable to exhibit learning during the task, this will suggest that there are underlying learning deficits such as implicit and procedural learning that contribute to language abilities and performance on a gesture sequence task.

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ACADEMIC VITA of Kaitlyn P. McCaffrey

Kaitlyn McCaffrey
348 Blue Course Dr., Apt 310
State College, PA 16803
kpm5085@psu.edu

Education:

Bachelor of Science Degree in Communication Sciences and Disorders
Penn State University, Spring 2012
Honors in Communication Sciences and Disorders
Thesis Title: Implicit and Sequential Learning in a Motor Sequence Task
Thesis Supervisor: Dr. Carol Miller

Related Experience:

Research Assistant for Penn State's Department of Communication Sciences and Disorders
Supervisor: Dr. Carol Miller
Fall 2010, Spring/Fall 2011 and Spring 2012

Undergraduate Teaching Assistant for Penn State's Department of Communication Sciences and Disorders
Supervisor: Dr. Krista Wilkinson
Fall 2011

Awards:

The President's Freshman Award
Alumni Recognition of Student Excellence Award
Dean's List 8/8 Semesters

Activities:

Treasurer of the National Student Speech Language Hearing Association
ELL Tutor for the Mid-State Literacy Council
Member of the Health and Human Development Honor Society
Committee Member for the Penn State Panhellenic Dance MaraTHON