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The Design and Validation of a Rhythm Span Task

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THE DESIGN AND VALIDATION OF A RHYTHM SPAN TASK

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Abstract

The purpose of this study was to design and validate a rhythm span task. Existing rhythm span tasks do not address important elements of rhythm and music such as tempo (speed), length (duration in beats per minute), and complexity (level of syncopation). This rhythm span task includes every combination of these criteria. The rhythmic sequences were presented with a piano sound from computer audio speakers. To align with traditional simple span tasks, the rhythm span task required participants to reproduce the rhythmic sequence. Results from this study showed that length was a significant factor for difficulty. Short rhythms were found to be mostly easy to reproduce while medium and longer length rhythms were more difficult to reproduce. The results also showed that number of musical elements, or tones, in rhythms increased as difficulty increased. Using the results from this study, a complete rhythm span task has been sequenced according to difficulty.

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Chapter 1

Introduction

The human memory system allows individuals to recall events and information over a span of time. The process of memory includes several sub-processes and functions that work in tandem to create the overarching concept of memory. Memory functions to help us remember important events, like birthdays, and information that is learned in school, like spelling or math equations, and is something that we use daily. The human memory system processes everything around us, including the language we hear and the things we see (Baddeley, 1992). Information that is received is processed through multiple memory components that include short-term memory, working memory, and long term memory. Rhythmic memory is a concept that has not been studied extensively. Because memory for rhythmic information has been studied so little, there is no span task that accurately measures rhythmic working memory span. This study will focus on working memory and its role in rhythmic memory.

Working memory is a unique component of the memory model that processes information for a short amount of time with the ability to manipulate the information, if necessary, and conduct other cognitive tasks simultaneously. Therefore, working memory is distinguished by its ability to hold information while it is manipulated through processes like reasoning and comprehension (Baddeley, 2003). It is derived from the short-term memory model and filters the information that is being processed in the memory model and delegates the information to subcomponents of its system (Baddeley, 1992). Working memory is a system that is believed to have evolved from a need to temporarily store information that is task relevant during the completion of a task, not simply remembering a digit span such as a telephone number (Conway, Kane, Bunting, Hambrick, Wilhelm, & Engle, 2005). The Baddeley-Hitch (Baddeley,

1992) model of working memory includes four components of working memory. The central executive is a control system that delegates memory tasks to other systems. These other systems include the visual-spatial sketchpad, phonological loop, and episodic buffer. The visual-spatial sketchpad processes visual information, like what is seen in one's surroundings. The phonological loop processes verbal and auditory information, such as speech. The episodic buffer processes chronological information, such as a sequence of events.

The phonological loop is of particular importance because it is responsible for phonemic information and auditory materials (Gathercole & Baddeley, 1990) and has been proposed as the memory device that facilitates language acquisition (Baddeley, Gathercole, & Papagno, 1998). While many previous studies have focused on the phonological loop component of working memory in language memory, very little research has been conducted on the rhythmic element of language and music and its memory system (Saito, 2010). As Saito (2010) indicated, previous studies have discussed multiple elements of language such as pitch memory and have attributed their memory process to the articulatory control process. Therefore, this component may also be responsible for the rhythmic element of language and possibly musical rhythm.

The assessment of working memory and its span is usually conducted using span tasks. These tasks measure span by requiring retention of information in the working memory store and, in some tasks, completion of a second cognitive task while maintaining the information. These tasks are referred to as span tasks and can be simple or complex. One of the earliest span tasks was the digit span developed by Wechsler as part of his Adult Intelligence scale. Itis a simple span task (Wechsler, 1945).

Very little research on working memory and rhythms has been conducted, though some research has indicated that rhythmic memory is housed within the working memory system.

Previous research has indicated that the memory component responsible for rhythmic memory may be the phonological loop of the working memory model (as cited in Saito, 2010), possibly from the articulatory control component (Saito, 2010). If the phonological loop accounts for rhythmic working memory, then a working memory span task should be designed to measure rhythmic memory span.

Rhythm span tasks have been developed for a few studies. The tasks were designed to measure rhythmic memory; however, they fail to provide a deep understanding of rhythmic memory span. Previous rhythm span tasks consisted of rhythms that overlooked components that would provide a more accurate depiction of rhythmic memory. First, the rhythm span tasks to date have been created using computer generated rhythmic elements which are not a natural representation of rhythm and may not be maintained in the memory system the same as a naturally occurring rhythm that has been created by some type of musical instrument. Second, most spans have not included multiple rhythmical elements like length, speed, and complexity (e.g., syncopation). Finally, previous tasks fail to require reproduction of the presented rhythms, which is a key component in understanding what makes a rhythm difficult to recall.

The purpose of the current study was to create a rhythm span task that provides a more accurate depiction of rhythmic working memory. To address the absence of variation of rhythmic trials of previous rhythm spans, this new task was designed using three different rhythmic or musical elements: length, speed, and complexity. Each of these elements was addressed at three levels (e.g., the element of length was addressed as slow, medium, or long; tempo was addressed as slow, medium, or fast; complexity was addressed as straight, syncopated, or a mix of straight and syncopated). These nine levels of variation resulted in more unique rhythms and more natural rhythmic sounds. Furthermore, the rhythm span task was developed using a natural, piano sound. This method ensures a more natural sound to the rhythms, compared to existing rhythm tasks which used computer-generated tones. Lastly, the designed task required participants to reproduce the presented rhythms which is analogous to other memory span tasks (e.g., digit span).

This study was designed to determine what makes a rhythm challenging from a memory perspective. Rhythm is composed of several musical elements, like length (e.g., how long the sequence is), tempo (e.g., how fast or slow the rhythm is presented), and complexity (e.g., how syncopated the sequence is). is. A single element or a combination of elements could be responsible for rhythm difficulty.

This study has also been designed to answer the question, what is the average or typical span for rhythms. Other span tasks have resulted in a number, "seven" for example, that is assigned to an individual to represent working memory span (see Miller, 1956). Therefore, the rhythm span task has been designed to help determine what "seven" is for rhythmic working memory. In other words, how big is a person's rhythm span?

The resulting rhythm span task should be of interest not only to memory researchers, but also to educators. Music education is an important part of the PreK-12 curriculum. Research has demonstrated that exposure to music education increases students' oral vocabulary and grammatical understanding (Runfola, et al. 2012), however music education programs are frequently eliminated from the curriculum when a school is faced with budget shortfalls (Slaton, 2012). Investigating the role that memory for rhythm may play from a developmental perspective in terms of whether students who participate in music education programs experience enhanced memory for content other than rhythms, could help to support the importance of maintaining music education in the curriculum.

Chapter 2

Literature Review

Memory

Several years before Alan Baddeley titled the short-term memory system as "working memory", interest had been sparked and the concept had been studied. This interest has led to several discoveries about working memory that have shaped the system that we recognize today and interest continues to grow as new research emerges. The working memory system is fascinating because we use it constantly, often without realizing it. The working memory system is responsible for our memory of lists. For example, when one chooses not to write down a grocery list and maintain it in memory instead, the working memory system is being used. This system also helps us to follow instructions and maintain important information in multiple settings. Memory for rhythms has a place within the working memory system and the creation of a rhythm span task would help to better understand its place. This literature review has been designed to provide important information about the working memory system, working memory span and the tasks used to assess span, and previous research on working memory tasks for rhythms.

The working memory system was first conceptualized when Atkinson and Shiffrin (1968) used the term to describe their short-term store model. Baddeley and Hitch (1974) built upon this model when they developed a multi-store model of what is now known as the working memory system.

The Baddeley-Hitch (1974) model of working memory is a multi-store model and is a derivation of the short-term memory system. The model consists of several components. These components interact to store and manipulate information on a deeper level than short-term memory, which serves to hold information for a short period of time with no cognitive manipulation or involvement of a secondary cognitive element like mental calculations, for example.

The component at the helm of this model is the central executive. This component acts as a coordinator for its subsystems, which will be described subsequently. The central executive is the least well understood component of the working memory system. Until recently the central executive was simply described as a homunculus or a system that decided how its subsystems worked (Baddeley, 1996; Baddeley, 2001a). Little is known about the components of the central executive beyond its two attentional control components: 1) the supervisory activating system and 2) dividing of attention (Baddeley, 2001a).

In 1986, Norman and Shallice proposed the supervisory activating system. Baddeley used this component in his model for the central executive. Evidence for this system indicated that it intervenes when routine attentional processes are insufficient (Baddeley, 2003). Baddeley provides an example stating that the supervisory activating system is apparent when routine processes, such as driving to the office, override more infrequent processes, like driving to the store. Baddeley (2001a) states that this system accounts for two phenomena: 1) absentmindedness and 2) disturbances to attentional control arising from frontal lobe damage. This system is important because it provides a link between long-term memory integration with working memory by refreshing relevant information from the long-term memory that applies to the current task, a process that is inhibited after frontal lobe damage (Baddeley, 2001a).

Baddeley (1996) attributed the process of dividing attention to the central executive. This effect was primarily demonstrated in people suffering from Alzheimer's disease because their long-term episodic memory was impaired and they had attentional impairment. Baddeley then indicated that there may be a separate system in the central executive that controls how attention is divided. Although little more than this is known about the central executive, Baddeley (2003) maintains that the central executive is possibly the most important component of the working memory model because it is responsible for coordinating three extremely important subsystems: 1) the episodic buffer, 2) the visuospatial sketchpad, and 3) the phonological loop. Each subsystem will be described in turn.

One subsystem of the working memory model has been labeled as the episodic buffer. This system is a limited capacity component of the model. It serves to integrate information that is provided or encountered chronologically or episodically between the long-term memory and working memory sub-systems and is assumed to be controlled by the central executive (Baddeley, 2001b; Baddeley, 2003). The episodic buffer integrates information from separate sources through multi-modal coding (Baddeley, 2001a). Baddeley (2001a) describes this as a mnemonic system that enables multiple sources of information to be considered simultaneously. The multiple sources of information and multi-modal coding processing are the reason for the limited capacity for the episodic buffer (Baddeley, 2001b). Baddeley also states that information in this system can be retrieved by conscious awareness. Since the buffer stores and integrates information chronologically, it captures life events as episodes and thus is referred to as the episodic buffer (Baddeley, 2001b). While this system is presented as a subsystem, Baddeley (2003) provides an alternative explanation for the episodic buffer, theorizing that it may also be a storage system for the central executive.

The visuospatial sketchpad is a sub-system of the Baddeley-Hitch model of working memory. The visuospatial sketchpad has not been as extensively studied as the phonological loop, likely because there are fewer techniques available to study it (Logie, 1986). However, neuropsychological evidence has been used to support the notion that it is a multicomponent system (Baddeley, 2001a). The proposed system includes the occipital lobe, which is responsible for our visual system; the parietal lobe, which is responsible for visual attention and integration of senses; and the frontal lobe, which is responsible for reasoning and organizing information. The visuospatial sketchpad is responsible for maintaining information as "what" the element is, meaning the visual processing of the element, and "where" the element is, meaning it's spatial location (Henry, 2010). While there is little research regarding this system, it has been proposed that there are separate components that are responsible for visual and spatial processing, therefore making the visuospatial sketchpad a multicomponent system. Logie (1986) suggested the visuospatial sketchpad had multiple components, indicating separate visual and spatial working memory components housed within it. The visuospatial sketchpad maintains spatial awareness and is used to help solve the problems that arise in the visuospatial world (Baddeley, 2001a).

As Baddeley (2003) states, visual surroundings serve as their own memory component and they typically persist over time and, therefore, make visual memory somewhat redundant. This system has a limited capacity and can maintain only three to four objects at a time (Baddeley, 1992, 2003; Logie, 1995). Like the phonological loop, the information held within the visuospatial sketchpad can be maintained for longer with rehearsal (Henry, 2010). This process has been proposed to be like the articulatory rehearsal function of the phonological loop and a passive store (Frick, 1988), though there is little known as to what these components may be or for what they may be responsible.

The phonological loop is the most extensively studied sub-system of the working memory system and, consequently, is understood the best. This sub-system is responsible for verbal activity and is comprised of two components: 1) the phonological store and 2) the articulatory rehearsal process. The phonological store is responsible for maintaining auditory information in the system for a few seconds before it fades. These memory traces can be maintained via a rehearsal process, typically referred to as sub-vocal rehearsal. The phonological store was first proposed to explain the phonological similarity effect that had been demonstrated in short-term memory research. This previous work indicated that letters that were similar phonologically, or sounded similar, were less likely to be remembered than dissimilar letters. For example, a string including W, X, K, R, Y, and Q should be easier to remember because they are phonologically dissimilar compared to a string that consists of V, B, G, T, P, and C (Baddeley, 2003). Logie, Della Sala, Laiacona, Chalmers, and Wynn (1996) demonstrated the phonological similarity effect on immediate verbal recall. The effect of phonological similarity decreased the verbal memory span of participants.

The articulatory rehearsal process was proposed to account for the word length effect. The word length effect arises when longer words or sequences are remembered less well than short words or sequences (Baddeley, 2001a). The word length effect was demonstrated by Baddeley, Thomson, and Buchanan in 1975. A series of experiments demonstrated that increases in word length or word length sequences resulted in poorer recall performance. Specifically recall ability decreases as word syllables increase from one to five. Baddeley et al. (1975) demonstrated this by compiling several lists of either one or five syllable words. These lists contained four to eight words and each list was read to the participant who was then asked to recall the words. Results indicated that the one syllable words were more easily recalled than five syllable words and that as the number of words increased, recall decreased regardless of word length. This study supported the word length effect and its role in the phonological loop.

To account for the word length effect, Baddeley et al. (1975) proposed the articulatory rehearsal process. The capacity of this system is approximately two seconds, regardless of sub-vocal rehearsal (Logie, 1995). The articulatory rehearsal process takes place in real time and when more data are added, earlier items fade (Baddeley, 2003).

Another element related to the articulatory rehearsal process is articulatory suppression. Articulatory suppression occurs when an individual speaks, typically repeating an irrelevant word, as to-be-remembered content is presented. This irrelevant speech inhibits memory for the relevant items. The effect of articulatory suppression was demonstrated by Baddeley, Lewis, and Vallar in 1984. Several experiments were designed using lists of words that were either phonologically similar (like cat and bat) or phonologically dissimilar (like cow and day). Lists of these words were read aloud to participants who were required to the repeat digits one through four subvocally while attempting to remember the words. At the conclusion of the list, the participants were asked to recall the words. Results indicated that articulatory suppression made recall more difficult. This demonstrated the role of articulatory suppression in the phonological loop.

In summary, the Baddeley-Hitch model of working memory consists of four components: 1) the central executive, 2) the episodic buffer 3) the visuospatial sketchpad, and 4) the phonological loop. Figure 1 provides a visual representation of the Baddeley-Hitch model of working memory. The working memory system is limited in span, meaning that only a certain amount of information can be held in the system at a given time.

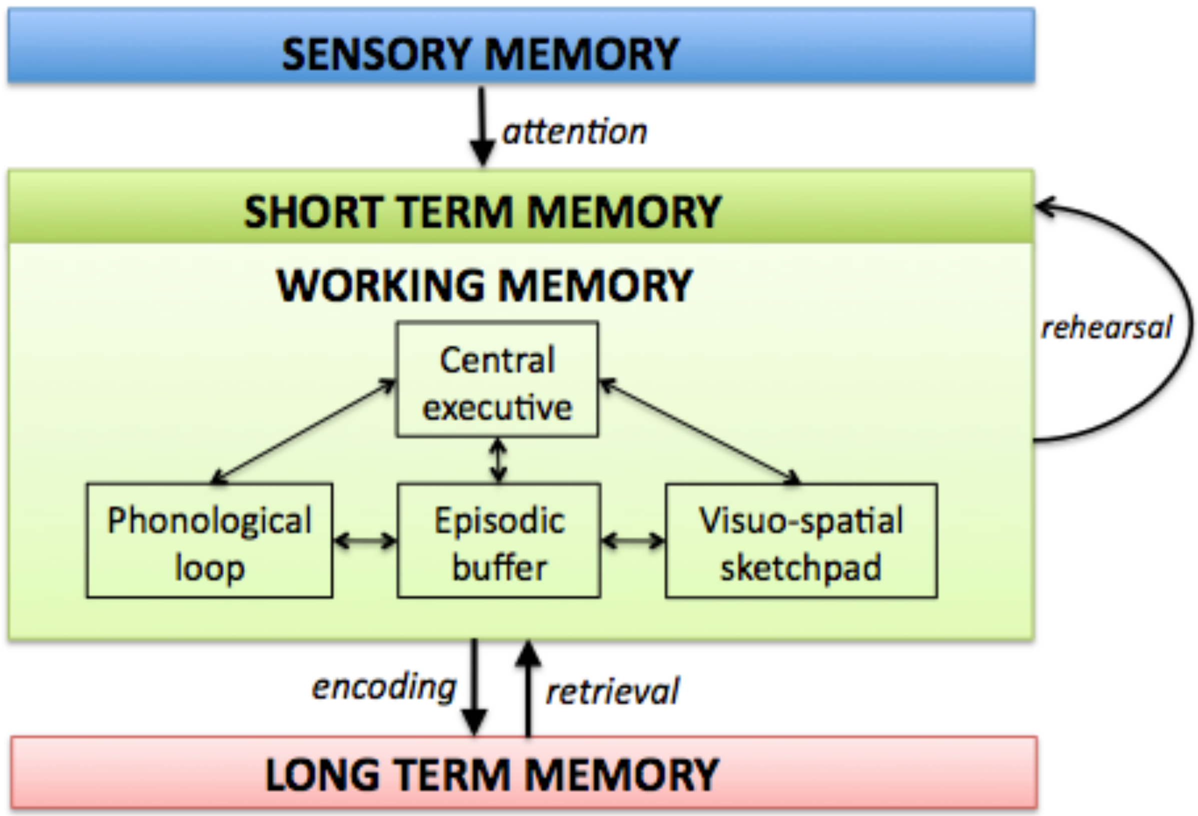


Figure 1. A representation of the Baddeley-Hitch working memory model ("Music in working memory", 2013).

Working Memory Tasks start here

Generally speaking, working memory span refers to the number of items or elements that can be held in working memory at any given time. Knowing how many items can be held in our working memory system is important because it helps us to understand how we communicate, learn, and develop. Working memory span was initially discussed by George Miller (1956) in his review of several working memory experiments. As the working memory system was conceptualized, span tasks began arising. Most of the tasks used today are designed around the Baddeley-Hitch model of working memory. These tasks include digit span, word span, reading span, operation span, and so forth. This review will focus primarily on verbal working memory span tasks.

George Miller (1956) started the discussion regarding span when he introduced the concept of the memory span being limited to seven, plus or minus two. Miller demonstrated that the number seven was conspicuously present in several psychological constructs that involved information processing, including immediate memory. By reviewing several experiments that aligned with his theory regarding the number seven, Miller demonstrated that the capacity for information processing and immediate memory was seven, plus or minus two. Miller referred to his work as capacity for information processing, however it aligns with working memory span. Therefore, this literature review will refer to his and others' research as working memory span and its associated span tasks.

When reviewing these experiments, Miller worked with a scale of measurement he referred to as *bits*. For reference, Miller uses the scale of bits to describe the amount of information that can be processed. Miller indicates that bits relate to the information we need to decide between different alternatives. So, to decide between two equally likely alternatives, we need two bits of information. Miller provides an explanation using height. If we are to determine whether a man is taller or shorter than six feet tall, we need one bit of information because we are deciding between two equally likely alternatives. From here, bits grow exponentially. To decide between three alternatives, we need eight bits, and between four alternatives we need 16 bits, and so on (Miller, 1956).

Miller first described this concept using unidimensional stimuli. In this context, unidimensional stimuli have one absolute judgement. These are simple, single judgments about things like the similarity of two items. Miller explored information processing for unidimensional stimuli by reviewing several experiments that required a single judgment between two options. Each of the reviewed experiments demonstrated that information processing revolved around the number seven.

The first experiment reviewed was conducted by Pollack (1952) and it investigated the similarity of tones. Participants were presented with a series of tones and were asked to assign numbers to each tone. These tones differed in frequency in equal steps. The results Miller discussed from Pollack's experiment indicated that participants were more inclined to confuse tones as the number of tones increased, specifically more confusions occurred at five or more tones. This supported Miller's observation of the number seven, plus or minus two, and its relevance in information processing and immediate memory. The work by Pollack demonstrated that the span for information processing fell within the limits of Miller's proposed number and indicated that information processing is limited.

In addition to Pollack's (1952) experiment on tones, Miller reviewed an additional experiment and concluded that information processing was limited to seven, plus or minus two in absolute judgment of unidimensional stimuli. These experiments included Garner's (1953) study on loudness, which indicated that span for loudness was five; Beebe-Center, Rogers, and O'Connell's (1955) experiment which lead to the conclusion that absolute judgment of taste intensities of salt solutions is four; and Hake and Garner's (1951) experiment which examined the absolute judgment span threshold for visual stimuli, specifically for two scale markers: They concluded that the span was 3.25 *bits*.

Miller also examined the number seven, plus or minus two, with respect to immediate memory. As Miller stated, "everybody knows that there is a finite span of immediate memory and that for a lot of different kinds of test materials this span is about seven items in length"

(1956, p. 348). This aligns well with Miller's theory of the number seven, plus or minus two, and he suggested that immediate memory and absolute judgments have an operational similarity. Miller also stated that if we can expect the span of immediate memory to be constant, "then the span should be short when the individual items contain a lot of information and the span should be long when the items contain little information," (1956, p. 348). As we have seen in previously described span studies (e.g., Baddeley, Thomson, & Buchanan, 1975), memory span decreases as the amount of information increases, just as Miller suggested.

To better understand the span of immediate memory Miller explained several experiments that modeled early span tasks. For example, Hayes (1952) used a procedure that was like a span task to determine immediate memory span. Five lists were developed comprised of several components including: binary digits, decimal digits, letters, letters plus decimal digits, and monosyllabic words. The lists were separately read aloud to subjects at one item per second, which is consistent with current span tasks. Hayes found that there were different spans for different material types. For example, binary items have a span of nine while monosyllabic words have a span of five. This result fell within Miller's proposed seven, plus or minus two, span limit. This same experiment was repeated by Pollack (1953), who achieved the same results.

Miller is careful to distinguish between bits and chunks. Chunks are commonly used as memory aids to group similar information together and, therefore, increase memory span. The process of developing chunks occurs via recoding. Recoding results in information being transmitted from the chunk it is currently in to chunks that are larger, with more *bits* per chunk. For example, a telephone number is often remembered in chunks. Typically, the number is recalled in three chunks: the area code, the first three digits, and the last four digits. Miller examined Sidney Smith's (1954) experiment to describe the process of recoding.

Smith (1954) devised an experiment that used recoding as a method to increase memory span of binary digits. The procedure required recoding several binary digits into octal digits (grouping three binary digits in a sequence together), therefore making the chunks of information fall within the span of working memory. Smith determined that the span of binary digits was 9 and the span of octal digits was 7, before the recoding procedure began. When 18 binary digits are recoded they become six octal digits and are, therefore, within the span of memory and within Miller's number seven, plus or minus two. Smith then presented binary and octal digit span tasks to 20 participants and gave five of those participants a recoding scheme. The results demonstrated that the process of recoding increased the number of bits per chunk to make the information easier to recall.

Miller's review of several absolute judgment and immediate memory experiments provided early groundwork and recognition of memory span and its limits, specifically its limitation of seven, plus or minus two. As psychological science has progressed this number has held constant and is seen in several current span studies. Individuals simply appear to have a memory span of seven, plus or minus two. In addition to memory span being limited to seven, plus or minus two, memory span is variable. Hunt, Lunneborg, and Lewis (1975) demonstrated that people with high verbal ability could more rapidly comprehend information in conversation than their low verbal counterparts. This evidence supported the limited span foundation of the working memory system as a variable feature that can differ from person to person.

To measure the working memory span of individuals, psychologists have used several memory span tasks. These tasks can be classified as simple or complex and can test various types of information. Digit span tasks are simple span tasks and some of the earliest and most common memory span tasks. The digit span task has been used for over a century in psychological research to assess memory, especially during IQ tests. The earliest use of the digit span was seen in 1912 when it was used to measure consciousness. The development of the digit span task most commonly used today can be credited to Wechsler. Wechsler (1945) developed a basic digit span task that measures working memory span using a series of numbers. In the digit span task as it is now, a series of digits is read aloud to a participant who is asked to maintain this information in the memory system. For example, the task may start with a list of four digits and increase to a list of ten digits by the conclusion of the test. The participant is asked to recall the digits provided after each list of digits and this continues as the number of digits increases. The number of digits a person can correctly recall demonstrates their memory span. The experiments that Miller reviewed demonstrated that memory span is limited to seven, plus or minus two.

A common variation of the digit span task is the word span task. In a word span task digits are replaced with words and read aloud (Conway, et al 2005; Turner and Engle, 1989). Like the digit span task, the number of words increases in subsequent lists and the participant is asked to recall as many words as possible after each list. Again, the maximum number of words correctly recalled by the participant is the memory span for words. These tasks are verbal and assess the phonological store.

While some simple span tasks may assess the phonological loop, there are similar tasks designed to address the visuospatial sketchpad. These tasks are developed around visually presented material and how much visual material can be stored in the working memory system. An example of a visuospatial simple span task is the Corsi Block Tapping task. This task was developed by Corsi (1972) and current configurations incorporate block image presentations on a computer. During the task, several blocks are presented on a computer screen in various locations. The number of blocks presented on the screen increases over trials. The task may start with four blocks in a sequence and increase to eight blocks in a sequence. The number of block locations recalled correctly after presentation reflects the spatial memory span of the individual.

Complex span tasks involve procedures like simple span tasks, but they include a secondary cognitive task. These complex tasks typically provide a list of to-be-remembered information to a participant who is then asked to complete a secondary task while maintaining the list. These secondary tasks may include reading or math tasks that tax the working memory system by placing additional demands on its processing centers. The individual must then recall the original list of to-be-remembered items. Recall may be affected by the addition of the secondary task. These tasks are good measure of working memory because the working memory system can maintain information while cognitively manipulating it (Macnamara, Moore, and Conway, 2011; Unsworth and Engle, 2007).

An example of a complex span task is Daneman and Carpenter's (1980) reading span task. The reading span task is administered as a simple word span task that is followed by sentence comprehension (Conway, et al 2005). The task begins with participants reading provided sentences aloud at their own pace, while maintaining the last word of each sentence in memory for later recall. The sentences provided vary in length from 13 to 16 words and each sequence of sentences ranges from two to six. Sentences are presented until participants fail to recall all the items of a given list size (Conway, et al 2005). This task is an important complex span task because it measures memory span by incorporating a secondary cognitive task along with a simple word span task. This task is different from a simple span task because it requires participants to maintain the words in their working memory while they are engaged in a secondary task, therefore requiring both maintenance and processing.

Span tasks can be categorized as simple or complex. Simple span tasks include digit and word span tasks, which include the presentation of elements in increasing amounts. Complex span tasks include the same presentation of elements as a simple span task, but include a secondary cognitive element such as reading or math calculations. Memory for rhythm sequences is among the variety of span tasks that have been developed. This review now turns its attention to this research.

Music

Music is composed of several elements. These elements, like instrument notes, interact to form a piece of music that has rhythms, harmonies, and melodies along with rests and accents. Rhythm is an integral component of sound. It is a systematic arrangement of sounds and silences that may vary in tempo (e.g. speed), duration (e.g. length), and/or complexity (e.g., syncopation). We hear rhythm in language and music and see it in movement. When people speak, their voices have a natural rhythm made of word syllables and pauses that we process as they speak, which is called prosody. As with any information we attend to and process rhythm has a span. The development of a rhythm span task is the focus of this study.

Existing rhythm span tasks.

While some researchers have investigated the link between working memory and rhythm, very few have developed rhythm span tasks. A search of the research resulted in five rhythm span tasks, all of which are included in the following review. They have been clustered in this review by their rhythmic elements (e.g., complexity, length, and tempo), their delivery method and construction, and their memorial element as recall or reproduction (Hall & Gathercole, 2011;

Jerde, Childs, Handy, Nagode, & Pardo, 2011; Saito, 2010; Schaal, Banissy, & Lange, 2014; & Wallentin, Nielsen, Friis-Olivarius, Vuust, & Vuust, 2010).

Saito (2010) conducted a study that used a rhythmic memory task in addition to several secondary memory tasks. The rhythm span task was developed using tonal sequences of sound and silence. Twenty-four rhythmic patterns were developed. The rhythms were presented on a computer. Participants were instructed to listen to the rhythmic pattern and to reproduce the rhythm by tapping a key on a computer keyboard when prompted. Secondary tasks, including an auditory digit span, visual digit span, articulation speed task, reading speed task, and mental rotation task were conducted after the rhythm task to measure the phonological loop and working memory span. Saito reported that rhythmic memory span is significantly positively correlated with auditory and visual memory span (Saito 2010).

A study conducted by Wallentin et al. (2010) examined the differences between musicians and non-musicians in melodic and rhythmic memory. They used the Musical Ear Test (MET) to examine the differences. The MET is comprised of both melodic and rhythmic elements which are presented to participants. The rhythmic element of the MET consists of four to 11 beats presented at 100 beats per minute which are created using wood block sounds. The sequences are presented in sets and the participant is asked to determine whether the sets are identical. The MET was used by Wallentin et al. (2010) in three experiments that used recognition and replication as recall. The results from this study indicated that musicians outperform non-musicians when identifying melodic and rhythmic elements in both recognition and replication. In addition, they indicated that the MET can be used to distinguish between amateur and professional musicians (Wallentin et al., 2010).

Jerde et al. (2011) developed a rhythm span task and used it to identify which areas of the brain are engaged when rhythm and melody are encountered. Their experiment consisted of rhythm and melody tasks. The rhythm task was comprised of sequences that lasted four seconds. They were conducted in common time (4/4) at 120 beats per minute. The rhythmic elements included quarter, eighth, and sixteen notes as well as eighth note triplets. The recall format of the experiment was recognition. The results from Jerde et al. (2011) suggested that several brain areas and systems were involved in music listening, resulting many subtle patterns in activation. These areas include the cerebellum, right anterior insular cortex, and the left anterior cingulate cortex

Hall and Gathercole also developed a rhythm span task (2011). Their task was developed to measure how rhythmic recall was affected by concurrent articulation and paced finger tapping (Hall & Gathercole, 2011). They conducted an experiment to measure the effects of concurrent articulation and paced finger tapping during rhythm presentation and memory performance. They designed their rhythm span task using Anvil Studio and the acoustic bass drum. The task used these tones to create rhythms of specific lengths (in milliseconds) such as short, medium, and long. The rhythms that were used were in common (4/4) time and at a tempo (speed) of 120 beats per minute. A total of twelve rhythmic sequences were used. The recall format of the task was reproduction. The results from this task demonstrated that concurrent articulation disrupted memory recall more than paced finger tapping. This suggests that “subvocal articulation is used in both verbal serial recall and recall of rhythms,” (Hall & Gathercole, 2011).

Schaal et al. (2014) developed a rhythmic task to measure span differences between musicians and non-musicians. The task was developed using a computer program that incorporated actual musical notes of varying lengths (quarter, eighth, sixteenth notes, as well as eighth note triplets). The rhythm trials consisted of two to ten rhythmic elements. A pitch task was also included to compare performance between the two tasks (Schaal et al. 2014). The last component consisted of a self-report questionnaire developed to measure musical training and musical sophistication. The rhythm task was administered using a computer and used recognition as a recall format. The results from this task showed that musicians significantly outperformed non-musicians on rhythm span (Schaal et al. 2014).

The five rhythm tasks described above were designed using short, uncomplicated rhythms. A summary is provided in Table 1. When complexity was included through the addition of eighth note triplets, they were either very slow (60 bpm) or recorded using wood blocks, which would not accurately depict the length of a note. In addition, their recall elements were either recognition, by indicating which rhythm was the same as the target rhythm, or replication, by recreating the rhythm presented to the best of the participant's memory.

A rhythm span task should include a natural sound that mimics what listeners hear when encountering musical rhythms. A rhythm span task should also include the elements of length, speed (or tempo), and syncopation (complexity) (Akiva-Kabiri et al., 2009; Krumhansl, 2000). These three elements are naturally found in rhythms and should, therefore, be included in rhythm span tasks. In addition, a rhythm span task that includes all three of these criteria should include enough trials to accurately measure memory for rhythm with respect to length, speed, and complexity. Finally, a rhythm span task should require the participants to recall the rhythm themselves and reproduce the rhythms to fit with commonly used simple span task techniques. To date, nothing has been developed that meets these criteria in a single task.

Table 1.
A summary and critique of five rhythm span tasks.

Researcher	Task Elements					Results	Critique
	Varied Length	Varied Tempo	Varied Complexity	Reproduction	Natural Sound		
Saito (2010)				X		Rhythmic memory is closely related with the phonological loop. It correlates with auditory and visual memory span.	This rhythm span task does not use various lengths, tempos, and complexity in addition to using computer tones.
Wallentin, Nielsen, Friis-Olivarius, Vuust, & Vuust (2010)	X		X	X		Musicians outperformed non-musicians in identifying rhythms, recognizing and replicating rhythms, and that as age increases memory span decreases.	This rhythm span task did not use natural sounding elements and used only one tempo.
Jerde, Childs, Handy, Nagode, & Pardo (2011)			X			Several brain areas are activated when listening to rhythms including: the cerebellum, right anterior insular cortex, and the left anterior cingulate cortex.	This rhythm span task only varied complexity, not length or tempo, used non-natural sound and used recognition.
Hall & Gathercole (2011)	X			X	X	Concurrent articulation disrupts memory recall more than paced finger tapping when recalling rhythms, indicating that subvocal articulation is used in recall of rhythms.	This rhythm span task is very close to an ideal rhythm span task, but does not use variation in tempo or complexity.
Schaal, Banissy, & Lange (2014)			X			Musicians significantly outperform non-musicians on rhythm and pitch spans, and had higher measures of musical training and sophistication.	This rhythm span task uses a variety of tempos, but does not vary in length or complexity. This task also does not use natural sound or reproduction for recall.

Developing a New Rhythm Span Task

The current study addresses the elements needed to develop a rhythm span task. To do so, a rhythm span task should consist of rhythms created in a systematic arrangement of sounds and silences that may vary in tempo (e.g. speed), duration (e.g. length), and/or complexity (e.g., syncopation).

Elements of rhythm.

Several components of music create rhythms including: length, tempo, and complexity. Length is the number of bars/measures of a given rhythm. Rhythms can consist of one or several measures and an entire piece of music is composed of many measures. In addition to length, rhythms have a tempo. Tempo is the speed of the music, typically measured as beats per minute (bpm). Common tempos are 60, 90, and 120 bpm. Rhythm is also defined by its complexity. Complexity refers to the degree of syncopation present within the rhythm. Syncopation is the placement of stress or accents on the weak beats of a measure. Rhythms can have varying levels of syncopation.

A viable rhythm span task has been created based on the definition of a rhythm: a systematic arrangement of sounds and silences that may vary in tempo (e.g. speed), duration (e.g. length), and/or complexity. First, this new span task has been developed in accordance with previous, well-established memory span tasks (e.g., digit span, word span, reading span). This means that a rhythm span task should require that participants reproduce, rather than recognize, the span elements. Second, rhythm span tasks should use real musical sound (not artificial) as much as possible. Music is typically heard as an instrument or voice. Artificial sounds (e.g. computer tones) may not be as easy to relate to music. For example, although striking wood blocks presents a “rhythm,” the duration of each note cannot be determined. This means, for example, that it may be difficult to notice a difference between a quarter or half note when using rhythm sticks. Therefore, a more natural musical sound, like notes from a piano keyboard, should be used so that the musical note duration information is maintained. Third, span tasks should use varying lengths and speeds in their trials. Rhythm sequences may be long or short, fast or slow, simple or complex. A rhythm span task should incorporate these critical rhythmic elements.

Existing rhythm span tasks fall short in one or more ways. First, span tasks should incorporate reproduction as a recall element. Schaal et al. (2014), for example, asked participants to identify similar and dissimilar rhythmic sequences, instead of reproducing the rhythmic sequences they encountered. The use of recognition in a span task does not effectively measure the working memory span and therefore a span task that uses reproduction is necessary.

Second, span tasks should incorporate real, natural sound in their trials to be most consistent with music. The rhythm tasks developed by Schaal et al. (2014), Wallentin et al. (2010), and Jerde et al. (2011) used true musical sound. Their use of a variety of notes ranging from half notes to eighth note triplets is a more accurate representation of music. But, these tasks failed to address the other criteria of a rhythm span task including variations in tempo, duration, and complexity.

Third, span tasks should vary in tempo (e.g. speed), duration (e.g. length), and/or complexity. Saito (2010) developed a rhythm span task that measures rhythm memory span, but used tonal rhythms with little variation. The use of computer generated sound decreases the realistic nature of music and limits the music encountered to milliseconds versus how music is created. In addition, Schaal et al. (2014) and Jerde et al. (2011) created rhythm span tasks with little variation. Therefore, a task that has variation of tempo, length, and complexity is essential.

Hall and Gathercole's (2011) task aligned best with traditional span tasks. The task was developed using a relatively realistic sounding tone, though still artificial. The task explored the use of different rhythmic sequences lengths (short, medium, or long) and the task required participants to reproduce the rhythmic sequences. Taken as a whole, Hall and Gathercole's (2011) rhythm span task better matches typical span tasks like digit span or word span. Unfortunately, the task was designed using unrealistic (for music) time constraints because music is not heard as milliseconds, but as notes and rests. In addition, Hall and Gathercole's task did not include variations in complexity in the rhythm sequences. In addition, this experiment consisted of only 12 trials. For a rhythm span task to accurately measure rhythm span regarding the three important criteria and their levels, more rhythm sequences are likely required.

All the tasks discussed here fall short in measuring working memory for rhythm because each task is missing at least one important element. No task has been developed to measure rhythmic working memory span by using a natural, musical sound incorporating speed, length, and syncopation across several rhythmic trials with a reproduction requirement for recall. Since no existing task meets these criteria, a new span task has been developed and validated.

Chapter 3

Methodology

The purpose of this study was to design and validate a rhythm span task to accurately measure working memory span for rhythms. The function of rhythm in the working memory system can be illustrated with a well-developed rhythm span task. A better understanding of rhythm span could have implications in several areas of memory research including verbal memory, cognitive functioning, as well as implications for music education.

Rhythm is a systematic arrangement of sounds and silences that may vary in tempo (e.g., speed), duration (e.g., length), and/or complexity (e.g., syncopation). Rhythms are created with musical elements that include: length, tempo, and syncopation. Therefore, a rhythm span task has been created with three main criteria in mind: 1) length (short, medium, or long) which is measured by the number of measures or bars included in each trial; 2) tempo/speed (slow, moderate, fast) measured in beats per minute; and 3) complexity (simple, syncopated, or mixed), which refers to how complex the presentation of beats is in the music, whether on beat (simple) or having irregular beat placement (syncopated). A final important criterion when developing a rhythm span task is natural sound. Several rhythm span tasks have been developed using computer generated sound (Saito, 2010, Hall & Gathercole, 2011), but this type of sound is not how people typically encounter rhythms. Therefore, this rhythm task incorporates the types of musical sounds people are used to hearing. The purpose of this study was to develop a rhythm span task that aligns with each of these criteria.

Materials

Task development.

A rhythm span task has been developed to address the criteria described previously. The task consisted of 81 unique rhythms. These 81 rhythms have been categorized by how they meet the three important elements of rhythm (e.g., length, tempo, complexity), and have been designed using a matrix system to ensure each combination of elements is represented. The rhythmic elements discussed are broken down as follows:

1) Length is the number of bars/measures in the trial. Bars and measures are composed of beats. The length element consists of short rhythms (one measure consisting of four beats), medium rhythms (two measures consisting of eight beats), and long rhythms (three measures consisting of twelve beats).

2) Tempo, also referred to as speed, is the pace of the beats in the trial. These rhythms have been created in common time (four beats per measure) and at varying levels of beats per minute (bpm). Slow rhythms are 60 bpm. Moderate rhythms are 90 bpm. Fast rhythms are 120 bpm.

3) Complexity is the presence or absence of syncopation at varying levels in the trial. Syncopated music contains an irregular beat pattern, such as notes (sounds) falling on the weak beat. This means that emphasized sounds occur in an atypical position in the measure. Straight (simple) rhythms have no syncopation. Syncopated sequences are entirely syncopated. Mixed rhythms are a mix of straight and syncopated elements.

Each rhythm trial combines a different level from each of the three criteria to create rhythms that are representative of actual music. For example, one rhythm is short, slow speed, and straight. Another rhythm is short, medium speed, and straight. The rhythms included in the task were created using sheet music from several composed works. Using composed music is an appropriate way to create these rhythms as it is already natural music. Rhythms were created this way to comply with the matrix of rhythm criteria presented in Table 2. In addition to the combinations presented, mixed rhythms were presented in their original sequence and a flipped sequence. This means that if a mixed rhythm started with a straight (or non-syncopated) content, it was then reversed for an additional trial that started with the syncopated content. With the inclusion of reversed mixed rhythms, the final rhythm span task included 108 total rhythms.

The rhythms were created with an introduction of four beats from a metronome at the tempo of the trial. Following the four metronome beats, the rhythm trial began consisting of single pitch notes played with a piano sound from the software Garage Band. This software is for music creation using several types of instruments and tones. It allows the user to layer multiple clips, sounds, or instruments to create one musical sequence. Creating the rhythms with a classical piano sound resulted in a natural sounding sequence that more closely aligns with how individuals encounter rhythms outside of a research setting. In addition, using a piano sound rather than wood blocks (as did Wallentin et al., 2010) or a drum (as did Hall & Gathercole, 2011) maintained the duration of the note (such as a half note or whole note), which further maintained the natural sound of the rhythm. Three rhythm sequences were developed for each of the 27 combinations shown in Table 2 and Figure 2. A total of 108 rhythms were created.

Table 2.
All possible combinations of rhythm criteria

Combination	Tempo (bpm)	Length (measures)	Complexity (level of syncopation)
1	Slow	Short	Straight
2	Slow	Medium	Straight
3	Slow	Long	Straight
4	Moderate	Short	Straight
5	Moderate	Medium	Straight
6	Moderate	Long	Straight
7	Fast	Short	Straight
8	Fast	Medium	Straight
9	Fast	Long	Straight
10	Slow	Short	Mixed
11	Slow	Medium	Mixed
12	Slow	Long	Mixed
13	Moderate	Short	Mixed
14	Moderate	Medium	Mixed
15	Moderate	Long	Mixed
16	Fast	Short	Mixed
17	Fast	Medium	Mixed
18	Fast	Long	Mixed
19	Slow	Short	Syncopated
20	Slow	Medium	Syncopated
21	Slow	Long	Syncopated
22	Moderate	Short	Syncopated
23	Moderate	Medium	Syncopated
24	Moderate	Long	Syncopated
25	Fast	Short	Syncopated
26	Fast	Medium	Syncopated
27	Fast	Long	Syncopated

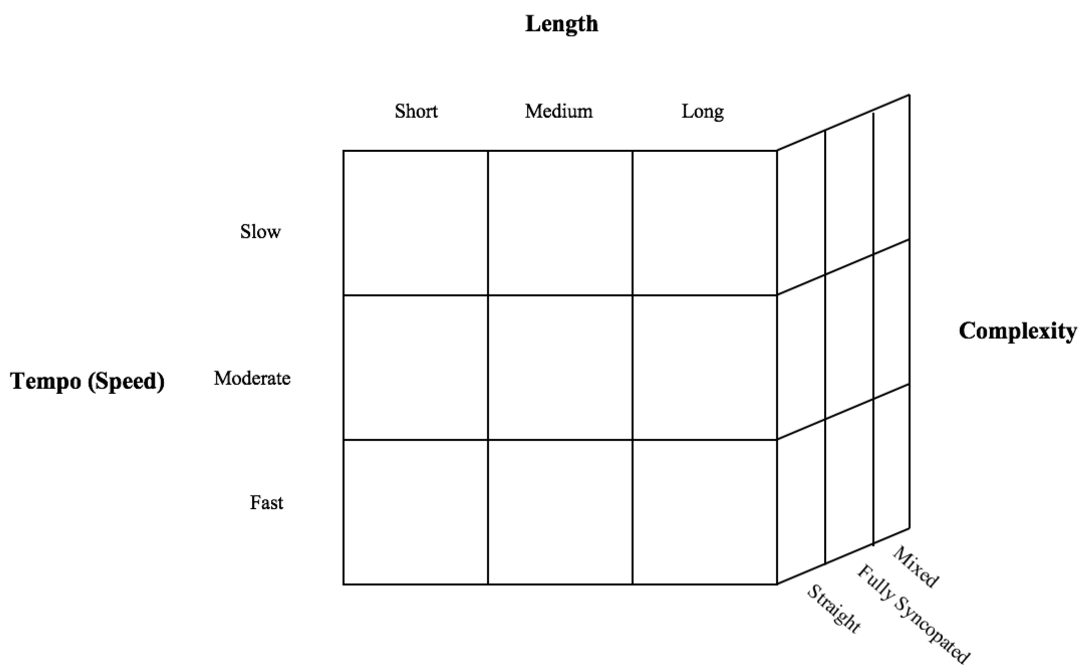


Figure 2. Representation of the combination of the three rhythm criteria and each of their respective levels.

The sequencing of rhythm trials was essential to determine which components of rhythm are most difficult to recall. In addition, determining the proper sequence of rhythm trials was essential to creating a valid rhythm span task because traditional simple span tasks start with easier (shorter) trails that increase in difficulty (length) as participants move through the task.

Work by Akiva-Kabiri et al. (2009) indicated that there was a "length effect" for pitch memory, which used a variety of rhythms. They found that long sequences of notes (long rhythms) were better recognized from a fast presentation rate, while short sequences of notes (short rhythms) were not better recognized from fast presentation. This suggested that longer rhythms with fast tempos and shorter rhythms with slow tempos are better recalled. A study conducted by Fitch and Rosenfeld (2007) examined syncopated rhythms and found that rhythms that were less complex, meaning less syncopated, were better encoded in the memory system and therefore better recalled.

The evidence from previous work on music memory provided an initial framework for sequencing rhythms according to difficulty for this rhythm span task. While the research provided a framework, there were still areas that were unclear. In order to determine the final easy-to-hard rhythm sequence especially for rhythm sequences that were difficult to place because the combination of elements did not fit well with placement suggestions from previous researcher, a group of musical experts were asked to examine sets of rhythms in a dichotomous decision task and to predict which rhythm in a set would be more difficult for the average participant to recall. These individuals were considered musical experts based on the amount of years they had spent in musical training, their aptitude with musical instruments, and their level of formal music education at a university. This group of musical experts consisted of 13 individuals who ranged in years of musical training from 10 to 70 years. Individuals played several instruments, including voice. In addition to playing several instruments, 10 had bachelor's degrees or master's degrees in music.

The dichotomous decision task is provided in Appendix A. This provided further information to support the sequencing of rhythm trials according to their difficulty. Table 3 provides the predicted sequence of rhythms according to predicted difficulty. Most straight rhythms were placed towards the beginning because they are likely easier to remember, while most of the syncopated rhythms were placed towards the end, because they are likely to be more difficult to recall. The musical experts also predicted that the short rhythms would be easiest, while most medium and long length rhythms were predicted to be more difficult. Most of the moderate and slow tempo rhythms were predicted to be more difficult to reproduce.

Table 3

Predicted Order of Rhythm Sequence Difficulty

1. Short, Slow Straight	19. Medium, Fast, Straight
2. Short, Moderate, Straight	20. Medium, Fast, Mixed
3. Medium, Moderate, Straight	21. Flipped, Medium, Fast, Mixed
4. Medium, Slow, Straight	22. Medium, Moderate, Mixed
5. Long, Fast, Straight	23. Flipped, Medium, Moderate, Mixed
6. Long, Moderate, Straight	24. Long, Fast, Syncopated
7. Short, Fast, Straight	25. Medium, Slow, Mixed
8. Short, Slow, Mixed	26. Flipped, Medium, Slow, Mixed
9. Flipped, Short, Slow, Mixed	27. Medium, Fast, Syncopated
10. Short, Fast, Mixed	28. Long, Moderate, Mixed
11. Flipped, Short, Fast, Mixed	29. Flipped, Long, Moderate, Mixed
12. Long, Fast, Mixed	30. Long, Moderate, Syncopated
13. Flipped, Long, Fast, Mixed	31. Medium, Moderate, Syncopated
14. Short, Slow, Syncopated	32. Medium, Slow, Syncopated
15. Short, Moderate, Syncopated	33. Long, Slow, Mixed
16. Short, Moderate, Mixed	34. Flipped, Long, Slow, Mixed
17. Flipped, Short, Moderate, Mixed	35. Long, Slow, Syncopated
18. Short, Fast, Syncopated	36. Long, Slow, Straight

The Goldsmiths Musical Sophistication Index (Gold-MSI), a musical ability and interest questionnaire, was used to determine participants' musical ability and to determine musical ability range across the sample. The Gold-MSI instrument was administered to participants after they completed the rhythm trials.

Additional information was requested from participants. Musical information included years of formal musical training, years of formal training in music theory, hours spent practicing a week, on average, and the number of instruments played. Demographic information requested included age, gender, ethnicity, occupational status, and education status.

Participant Sampling

Participants were sampled from a research management system at the university. These participants were enrolled in an educational psychology course that required three hours of research participation and included both undergraduate and graduate level students.

Procedure

Participants first completed the informed consent form. Following completion of the form, participants were briefed on the instructions for the task and they completed two sample trials. After the samples, participants completed the rhythm span task. The sample trials and task were presented using computer speakers. Each trial began with the sound of the four metronome beats in the tempo of the trial. After the four metronome beats, the rhythm trial began. After the trial, participants heard a recall prompt of the researcher's voice saying "recall." Participants reproduced the rhythms using a small, MIDI keyboard (which resembles 25 notes on a piano keyboard). Participant reproduction was audio recorded. After the completion of a trial, another trial immediately followed. After nine trials, participants received a one minute break to complete a non-competing cognitive activity. These activities were shadow matching puzzles. The breaks were included to help lower the burden on the working memory system and decrease interference from previous trials. Participants were randomly assigned to one of two groups: rhythms presented in the predicted easy-to-hard sequence or rhythms presented in a random order. After completing the rhythm span task, participants completed the Gold-MSI.

Scoring

Placement of the beats according to the presented rhythm were the main criteria for scoring. Rhythms were marked correct if 75% of beat placement matched the target rhythm. For example, for a rhythm consisting of eight rhythmic elements (notes), six elements accurately placed were marked as correct. Scoring of the rhythm span task was conducted by the experimenter on site, who has adequate musical training to determine the correctness of the reproduced rhythm. The experimenter had over 10 years of music training as a vocalist that includes four years of training in musical notation and sight reading and four years of piano training. After the initial scoring, a subset of rhythm trials was scored by an additional individual with adequate musical training to establish reliability of the scoring process. The second scorer had 10 years of classical piano training and 20 total years of playing piano. They also had three years of flute training. A third scorer was consulted with over 50 years of experience as a vocalist, 10 years of formal instruction in piano, and seven years of experience as a hand bell ringer.

Chapter 4

Results

Results for this study are discussed below. The sample is described first, followed by the scoring for the task. After this, a test of the differences between performance for both conditions is presented. Following the results of the test of differences are details on task performance and task difficulty. Finally, correlations for the rhythm span task and Goldsmiths-MSI are provided.

Sample

Ninety-three participants were sampled from a large, southwestern United States university. Of the 93 participants, 58 reported as female and 23 reported as male. Twelve participants did not identify their gender. Participants ranged from 18 to 56 years old. Approximately 62% of participants indicated they were at university as their occupational status, with others having employment as their main occupational status. Most participants, 49.5%, had at least completed high school, 21.5% completed an undergraduate degree, and 24.7% had completed a postgraduate degree. Fifty-six percent of participants had at least one year of formal training on a musical instrument and 57% of participants played at least one instrument. Demographics are displayed in Table 4.

Table 4.
Demographic information for the sample.

	N	Percent
Gender		
Male	23	24.7%
Female	58	62.4%
Did not report	12	12.9%
Occupational Status		
At University	58	62.4%
Employed	30	32.4%
Did Not Report	5	5.2%
Highest Education Level		
Completed high school	46	49.5%
Completed an undergraduate degree	20	21.5%
Completed a postgraduate degree	23	24.7%
Did not report	4	4.3%
Musical Training		
At least one year of musical training	52	55.9%
No musical training	39	41.9%
Did not report	2	2.2%
Instruments played		
Played at least one musical instrument	53	57.0%
No musical instruments played	38	40.9%
Did not report	2	2.1%

Scoring and Reliability

Reproduction of a rhythm trial was scored as correct when at least 75% of the elements (tones) within the rhythm was correctly reproduced. To establish inter-rater reliability, a subset of rhythms was independently scored by two musically trained individuals. Reliability was insufficient after the initial scoring and therefore the entire sample was rescored according to new scoring guidelines. These included: 1) use of musical notation for each rhythm while scoring and 2) addition of notes after the rhythm was marked incorrect. After a complete rescoring of the sample according to these new procedures, reliability was recalculated using the third scorer with over 50 years of musical experience. Reliability was calculated as percentage agreement at 91%. A Cronbach's alpha was calculated for internal reliability (α=.923).

Group Differences

Rhythms were presented to participants in either a random or sequenced order. Participants in the random condition heard rhythms in a randomized order that was unrelated to the rhythmic construction, combination, or predicted difficulty. Participants in the sequenced condition completed rhythms trials that were in a predicted order on an easy-to-hard continuum. The easy-to-hard rhythm sequence was determined as described in the methods section. Performance on rhythm span was analyzed separately for the easy-to-hard sequence group as well as the randomly determined sequence group. In addition, all data were combined and compared to the randomized and sequenced data. An independent samples t-test was conducted. The independent variable was group assignment (randomized group or sequenced group) and the dependent variable was the total number of rhythms correctly reproduced. There was no significant difference between the randomized group ($M = 45.41$, $SD = 12.89$) and the easy-to-hard sequenced group ($M = 50.43$, $SD = 15.54$) for overall performance on the rhythm span task

($t_{(91)}$ = -1.691, p = .094). Although a t-test is not typically used to determine equivalence of means, for this sample there is no evidence that the group means are unequal. Therefore, the data set was analyzed using all subjects combined.

Rhythm Sequencing

Results from the rhythm span task data were used to sequence the rhythms according to difficulty. There were three trials per combination, so this was calculated as the average number of trials correct per combination set. Difficulty values ranged from most easy, an average of 2.74 rhythms correct per set, to most difficult, an average of 0.09 rhythms correct per set. After sequencing, a threshold of 75% was used to determine whether a rhythm set was considered easy or hard because this compares favorably with how accuracy or "correctness" is determined for other, existing simple span tasks. These results were then used to determine an easy-to-hard rhythm sequence. This information is provided in Table 5.

Table 5

Rhythm combination set average difficulty scores for all participants, including the average number of elements per set

Rhythm Combination Set	Difficulty
1. Short, Fast, Mixed, 4.33	2.74
2. Short, Slow, Syncopated, 4	2.69
3. Short, Slow Mixed, 4	2.69
4. Short, Fast, Straight, 5	2.52
5. Flipped, Short, Moderate, Mixed, 4	2.47
6. Short, Moderate, Syncopated, 6.33	2.37
7. Short, Fast, Syncopated, 4	2.31
8. Flipped, Short, Fast, Mixed, 5	2.31
9. Short, Slow, Straight, 4.33	2.26
10. Short, Moderate, Mixed, 4	2.25
11. Flipped, Short, Slow Mixed, 5.33	1.95
12. Medium, Moderate, Straight, 5.67	1.95
13. Medium, Fast, Straight, 6.33	1.90
14. Short, Moderate, Straight, 4.67	1.87
15. Medium, Moderate, Mixed, 7.67	1.59
16. Medium, Fast, Mixed, 6.687	1.58
17. Flipped, Medium, Moderate, Mixed, 6.67	1.31
18. Flipped, Medium, Slow, Mixed, 7.33	1.25
19. Long, Fast, Straight, 10.33	1.17
20. Flipped, Medium, Fast, Mixed, 6.67	1.16
21. Long, Moderate, Straight, 11.33	1.07
22. Medium, Slow, Straight, 7.33	1.04
23. Medium, Moderate, Syncopated, 8	1.03
24. Medium, Slow, Mixed, 6.33	0.91
25. Medium, Fast, Syncopated, 9.67	0.78
26. Long, Moderate, Syncopated, 15	0.70
27. Long, Slow, Syncopated, 20	0.55
28. Long, Fast, Syncopated, 14.67	0.41
29. Long, Fast, Mixed, 13.33	0.37
30. Medium, Slow, Syncopated, 10	0.31
31. Flipped, Long, Moderate, Mixed, 13.67	0.26
32. Flipped, Long, Slow, Mixed, 13	0.24
33. Flipped, Long, Fast, Mixed, 13.33	0.20
34. Long, Slow, Mixed, 13	0.15
35. Long, Moderate, Mixed, 12.67	0.13
36. Long, Slow, Straight, 12	.090

Note. The break line indicates the 75% threshold of rhythm difficulty, separating the easier and harder combinations.

The results indicate that rhythms steadily increased in number of elements (the number of tones within each rhythm). All easy rhythms had six or less tones, while difficult rhythms had greater variability.

The general results for difficulty level per criterion can be interpreted as follows: first, slow and moderate tempos were the most difficult to reproduce; second, most short rhythms were easy to reproduce and, finally, most mixed and syncopated rhythms were difficult to recall. The results by rhythmic element are discussed in greater detail immediately below.

Tempo.

Nine of twelve slow rhythms were difficult for participants to recall. Rhythms that were easy were all short (4 or 5 tones) and rhythms that were difficult were all medium or long in length, except for one short rhythm. Moderate tempo rhythms were split in the same way, three were easy and nine were hard. All easy moderate rhythms were short, and the hard, moderate rhythms were medium or long, except for one short rhythm. Four fast rhythms were easy, and all short. All of the hard, fast rhythms were medium or long length. Generally speaking, sequences that were short and fast were easier to recall and longer, fast rhythms were more challenging.

Length.

Nearly all short rhythms (rhythms one measure in length) were easy for subjects to recall regardless of tempo or complexity. Only two short rhythms were considered difficult. All medium length rhythms (rhythms two measures in length) and all long rhythms (rhythms three measures in length were difficult to recall, indicating a significant length effect.

Complexity.

Two straight rhythms were considered easy, while the remaining seven were hard. Most short, straight rhythms were easy and all medium and long, straight rhythms were hard. All easy, mixed rhythms were short, while mixed rhythms that were medium or long were hard, with the exception of one short, mixed rhythm being considered hard. Syncopated rhythms were more difficult to reproduce. Three fell into the easy category and six fell into the hard category. All easy, syncopated rhythms were short, while all hard, syncopated rhythms were medium or long.

Elements.

All easy rhythms had six elements or less (see Table 6 in Appendix B). Rhythm elements are defined as the number of tones within a rhythm sequence and the average number of rhythm elements was calculated for each set of three rhythms trials for each combination. The easiest rhythms to recall included four to six elements. The hardest rhythm sets to recall had more range, and included some shorter rhythms that had four to six elements. Table 6 (seen in Appendix B) provides a breakdown of the average number of elements per rhythm combination in each criterion.

Correlations

Correlations were calculated for total rhythms correct, years of musical training, and subscale scores of the Goldsmiths-MSI (refer to Table 7). Total rhythms correct, meaning the total number of individual rhythm sequences recalled correctly for each participant was significantly correlated with active engagement on the Goldsmiths-MSI, ($r = .211$, $p < .05$). Years of formal musical training was positively and significantly correlated with the Goldsmiths-MSI active engagement, ($r = .301$, $p < .01$) and the Goldsmiths-MSI musical training subscales, ($r = .776$, $p < .05$). The Goldsmiths-MSI active engagement subscale score was positively and significantly correlated with all other Goldsmiths-MSI subscales. The Goldsmiths-MSI perceptual abilities subscale score was positively and significantly correlated with both the Goldsmiths-MSI singing abilities, ($r = .412$, $p < .01$) and the Goldsmiths-MSI emotions subscales, ($r = .388$, $p < .05$). The Goldsmiths-MSI singing abilities subscale was positively and significantly correlated with the Goldsmiths-MSI emotions subscales score, ($r = .381$, $p < .01$).

Table 7

Correlations matrix for relationships between total rhythms correct, years of musical training, and Goldsmiths-MSI subscales.

	1	2	3	4	5	6	7
1. Total Rhythms Correct	-						
2. Years of formal musical training	.078	-					
3. Goldsmiths Active Engagement Subscale Score	.211*	.301**	-				
4. Goldsmiths Perceptual Abilities Subscale Score	.171	.192	.334**	-			
5. Goldsmiths Musical Training Subscale Score	.201	.776*	.278**	.157	-		
6. Goldsmiths Singing Abilities Subscale Score	.187	.177	.576**	.412**	.131	-	
7. Goldsmiths Emotions Subscale Score	.169	.176	.601**	.388**	.218	.381**	-

* p<.05
** p<.01
Note: Sample range from 86 to 93.

Chapter 5

Discussion

The following section will provide further discussion on the results from this study and their importance. First, the goal of this study, to design an accurate rhythm span task, was completed. Second, rhythm difficulty and its implications for sequencing of a future span task have been considered. Third, results from this study align closely with well-known research within working memory span, specifically the sequence of previous simple span tasks and touches on Miller's work on the magical number seven, plus or minus two. Fourth, limitations from this study are described. Lastly, suggestions for future uses for the rhythm span task and how the task can further research and development are provided.

The goal of this study was to design and validate a rhythm span task. It was important to develop a task that more closely resembles traditional and well-established memory span tasks. This task was designed to include the fundamental rhythmic criteria of length, speed, and complexity. In addition to these criteria, this task was presented using a classic piano sound to mimic actual music as closely as possible. Finally, this task used reproduction as the recall component.

Previous studies have employed rhythm span tasks that do not adequately measure rhythmic memory span. Previously developed rhythm span tasks used non-natural sound and had limited range of rhythmic elements like length, speed, and complexity. Existing tasks typically asked participants to determine whether two rhythm sequences matched rather than requiring reproduction of the rhythm (e.g., Hall & Gathercole, 2011; Jerde, Childs, Handy, Nagode, & Pardo, 2011; Saito, 2010; Schaal, Banissy, & Lange, 2014; & Wallentin, Nielsen, Friis-Olivarius, Vuust, & Vuust, 2010;).

The existing tasks did not adequately measure rhythm span according to the criteria identified for this task. Therefore, a new rhythm span task was developed and validated. The new rhythm span task includes all important rhythmic criteria: tempo, length, and complexity. The criteria were configured into 36 unique combinations to create the new rhythm span task. The new task uses a natural, classic piano sound to mimic actual music as closely as possible. This task also requires participants to reproduce the rhythm trial as accurately possible, therefore the new task more closely aligns with traditional memory span tasks. This rhythm span task has been constructed to meet the criteria needed for a new task and improves upon past research to create a complete and adequate rhythm span task.

The results demonstrated that short rhythms were easiest to recall; 10 of 12 short rhythms fell into the easier-to-recall category. All medium and long rhythms were difficult to recall. This may be interpreted to mean that rhythmic sequence length has a tremendous influence on reproduction difficulty. As discussed before, the capacity of this system is approximately two seconds, regardless of sub-vocal rehearsal (Logie, 1995); Shorter rhythms fall within the capacity of this system better than longer rhythms. Results for tempo were more varied, but most moderate and slow tempo rhythms were difficult to recall, and any fast rhythms that were difficult to recall were longer. This is most likely because of the amount of time participants had to maintain the rhythm within their working memory system, which could exceed working memory limits. Results for complexity were also more varied and indicated that mixed and syncopated rhythms were slightly more difficult than straight rhythms to recall. The straight rhythms that were difficult to recall were mostly medium or long in length, which likely made them more difficult to recall as they had a longer time duration. Overall, when sequenced according to difficulty (Table 5), rhythm sets typically increased in number of elements (tones in each rhythm) from a small number of elements/tones to a large number of elements/tones, with the exception of five sequences that did not follow the expected pattern. This supports a length effect in terms of what makes a rhythmic sequence hard to reproduce.

The Goldsmiths-MSI subscales include: active engagement, perceptual abilities, musical training, singing abilities, and emotions. Results from this study, surprisingly, did not correlate with years of formal music training, meaning that years of formal music training and performance on the task were not related. This could be due to the self-report nature of the Goldsmiths-MSI. Rhythm span scores only correlated with active engagement with music, meaning that those more actively engaged with music performed better on the task. Results also indicated that the Goldsmiths-MSI subscales were significantly inter-correlated. The active engagement subscale was correlated with all subscales, meaning that having high musical engagement is related to musical perceptual abilities, formal music training, singing abilities, and emotions in music. The perceptual abilities subscale was positively correlated with singing abilities and emotions in music. This means that higher musical perceptual abilities are related to higher singing abilities and emotional engagement with music. The analysis also indicated that self-reported singing abilities were related to emotional engagement with music. However, the analysis indicated that perceptual abilities and musical abilities were not correlated, which was unexpected.

An analysis of the rhythm difficulty sequence indicates that five rhythm sets could be excluded from a future version of this task, if necessary, because they fall outside of the expected sequence. These rhythm sets have numbers of elements that are not in the correct order for the difficulty sequencing. For example, the "short-moderate-syncopated" rhythmic sequence, which had an average of 6.33 rhythmic elements, fell into the hard category and was between sets of four elements. Rhythm sets that could be excluded include: 1) short, moderate, syncopated; 2) short, moderate, straight; 3) long, fast, straight; 4) long, moderate, straight; and 5) medium, slow, mixed. All these rhythm combinations could be excluded because the average number of elements does not fall accurately within the sequence, so they do not follow the order from smallest to largest average of musical elements. The final version of this task should progress from the lowest average number of elements to the highest number of elements, because the results indicated that rhythms were more difficult when they had greater numbers of elements.

Theoretical Relevance

Results from this study indicated that rhythms became more difficult as number of elements increased. This furthered years of prior research on working memory span tasks and their sequencing from smallest to largest number of elements. Since all easy rhythms were short, there is some support for Miller and the magic number seven, plus or minus two. Miller (1956) reviewed several studies to determine that seven, plus or minus two, was the span of the working memory system in several constructs. This study demonstrated that virtually all the rhythms that were considered easy were short and consisted of less than seven tones, while more of the hard rhythms had seven or more tones.

This study demonstrated that as the length of the rhythm trial increased from one to three measures and, therefore, increased in the number of tones, rhythms became increasingly difficult to maintain in the working memory system. This was demonstrated by nearly all short rhythms being easy, while all medium and long length rhythms were considered hard. While some of the medium and long length rhythms had fewer than seven tones, they had longer time durations, which could have been more taxing on the working memory system.

Limitations

This study was limited in a few ways. First, this study used convenience sampling from a research subject pool. This meant that the researchers could not ensure that participants were equally distributed among years of musical training, instruments played, and time spent working with music. In addition, the sample size was smaller than intended. Including more participants could have further stabilized the difficulty values. Second, researchers were limited by a lack of prior research for rhythmic memory. Because there was little research related to rhythmic memory, it was difficult for researchers to accurately predict the difficulty of a rhythm set. Third, the Goldsmiths-MSI is a self-report measure for musical training and engagement. The researchers had to rely on what participants indicated for their years of musical training and instrumental expertise, which may not be accurate. Lastly, the reliability of this task was difficult to determine at first and, therefore, the task had to be rescored to establish reliability using more stringent scoring guidelines.

Utility

An adequately designed rhythm span task provides several options for future research and utility in various settings. This task has been developed to meet the criteria deemed necessary and is an adequately designed rhythm span task that can be implemented with future studies. Provided below are three possible uses for this rhythm span task that demonstrate how it could be used in future research for educational psychology, music research, and child development.

This newly designed rhythm span task has high utility in several settings. First, this rhythm span task could be used in further research to expand upon what little is known about rhythmic working memory. This task could be used to examine differences between types of musicians, like percussionists and vocalists, who may have noticeably different rhythm spans.

This task could also be used to determine differences between dancers, who deal exclusively with memorizing rhythm and classical musicians.

In addition to differences between groups of non-musicians, musicians, and less classically trained musicians, this task could be used to determine how rhythmic memory and the phonological loop are related. This task could be compared to other phonological loop span tasks to determine how verbal memory and rhythmic memory, which is potentially connected to language through phonetics, are related.

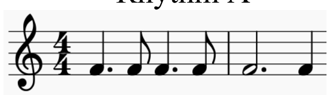
Finally, this task also has developmental research uses. This task could be used to determine differences between age groups of children and compared with performance on other cognitive tasks and academic achievement. Children who participate in dance or music may, for example, perform better on other cognitive tasks or span tasks, which may be related to higher achievement scores within classes such as reading or English.

Appendix A

The purpose of this research is to develop a rhythm task that uses musical elements like tempo, length, and complexity while using a natural sound, like a piano. This rhythm task will be administered to individuals that vary in musical ability and training. Many may have very little music experience. Please examine the following rhythmic sequences and assess their difficulty. Research subjects will hear the rhythm and will be asked to reproduce it. They will not see the music written out as you see in in this brief task. Your feedback will help to determine which rhythmic sequences will be more difficult to recall for the average participant.

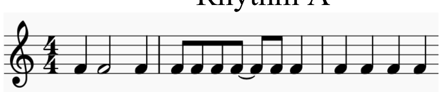
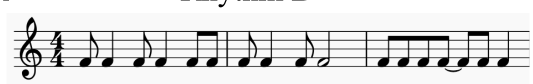
Please select the rhythm you think is most difficult for the average person.

1. Rhythm A OR Rhythm B



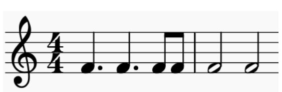

2. Rhythm A OR Rhythm B


3. Rhythm A OR Rhythm B

Please select which tempo would make it hardest to remember the following rhythms for the average person.

4.



Slow, 60bpm Moderate, 90 bpm Fast, 120bpm

5.

Slow, 60bpm Moderate, 90 bpm Fast, 120bpm

Please answer the following questions.

6. Are you a vocalist, instrumentalist, or both? ____________________

7. If you are an instrumentalist, which instrument(s) do you play?

____

8. How long have you been a musician? ____

9. If applicable, what is the highest degree you have earned and in which field?

____

Thank you for your participation!

Appendix B

Table 6

Average number of elements per criterion that were classified as either easy or hard

Criterion	Easy	Hard
Slow Tempo		
	4	5.33
	4	6.33
	4.33	7.33
		7.33
		10
		12
		13
		13
		20
Moderate Tempo		
	4	4.67
	4	5.67
	6.33	6.67
		7.67
		8
		11.33
		12.67
		13.67
		15
Fast Tempo		
	4	6.33
	4.33	6.67
	5	6.69
	5	9.67
		10.33
		11.33
		13.33
		13.33
Short Length		
	4	4.67
	4	5.33
	4	
	4	
	4	
	4.33	
	4.33	
	5	
	5	
	6.33	
Medium Length		
		5.67
		6.33
		6.33
		6.67
		6.67
		6.69
		7.33
		7.33
		7.67
		8
		9.67
		10

Long Length		
		10.33
		11.33
		12
		12.67
		13
		13
		13.33
		13.33
		13.67
		14.67
		15
		20
Straight Complexity		
	4.33	4.67
	5	5.67
		6.33
		7.33
		10.33
		11.33
		12
Mixed		
	4	5.33
	4	6.33
	4	6.67
	4.33	6.67
	5	6.69
		7.33
		7.67
		12.67
		13
		13
		13.33
		13.33
		13.67
Syncopated		
	4	8
	4	9.67
	6.33	10
		14.67
		15
		20

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