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Assessment of the Correlation between Memory Span Test Result and Attention using a Wireless EEG System

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Assessment of the Correlation between Memory Span Test Result and Attention using a Wireless EEG System

by

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We the undersigned committee hereby approve the attached thesis, "Assessment of the Correlation between Memory Span Test and Attention using a Wireless EEG System," by Yu Yu.

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Abstract

Title: Assessment of the Correlation between Memory Span Test result and Attention using a Wireless EEG System

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The process to encode, retain and retrieve information is known as memory. Ever since models for short-term memory and working memory systems were proposed, the function and importance of the short-term memory and working memory systems have been explored by a number of studies which in part have examined factors which may affect memory capacity. Although there are many undetermined factors which may affect the result of these two different memory span test, recent studies have suggested a link between human mental condition and memory capacity. These studies show that the results of simple memory span tests are improved when subjects are in a state of focus. These results suggest a correlation between the attention level in a state of focus and the result of memory span test.

The current study employed the NeuroSky MindWave headset to monitor and record the mental state of subjects while performing simple and complex memory span tests to understand the correlation between test results and the headset's measurements. This correlation is then used to design an application on Android Plate to provide an estimate of the memory ability of a subject while performing memory span tests.

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Keywords

Short-term memory

Working memory

Simple span test

Complex span test

Attention

NeuroSky MindWave headset

Smart phone application

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Chapter 1

Introduction

The ability to selectively process and retain accessible information is a critical aspect of the human cognitive system. Research on the form and function of human cognition is significant for clinical medical diagnosis, as well as for the analysis of electroencephalographs (EEGs); as such, many experiments have been designed to explore it. Current understandings of the system divide it into three functional parts: (1) the ability to process information from the environment (usually called attention), (2) the ability to retain information in an accessible state over time1 (usually called memory), and (3) the ability to use existing knowledge to analyze new information (usually called reasoning or judgment). In recent studies (Daryl Fougnie, 2008), two different memory-system models (short-term memory and working memory) have been presented and used to explain human memory system. Though there are many different memory span tests have been proposed, most of these tests can be divided into simple span tests (which measure short-term memory capacity) and complex span tests (which measure working memory capacity). Although both simple and complex span tests are used to measure subject's intelligence and memory capacity, lots of study had been made to determine which test result is more reasonable in intelligence test. In order to address the similarities and differences between simple span tests and complex span tests, it is first necessary to compare short-term memory and working memory in a theoretical context.

1.1 Short-Term Memory

Theoretical understandings of short-term memory assume a limited-capacity system that temporarily maintains and stores information and supports human thought processes by providing an interface between perception, long-term memory, and action.[2] For example,a traffic signal turns yellow while a vechicle is reaching the intersection. The driver's attention is drawn to this change in his or her environment. After the yellow traffic signal has been identified, the information is stored in short-term memory to await further processing. Next, information relevant to this situation, which has been learned and stored previously, will be recalled to form a relationship with the information stored in short-term memory. Once the relationship is built, the processing function of the cognitive system analyzes the current situation and dictates the next action, for example, braking..Storing and processing information often takes less than 10 seconds, which may explain why people respond quickly to a given stimulation and retain the information about this stimulation for some time, but forget it without rehearsal or practice. When individuals gain new information, its retention in short-term memory is temporary. The information needs to be re-coded and restructured for permanent storage. After re-coding, the conversion of information from the external environment to long-term memory, passing through the short-term memory, is complete.

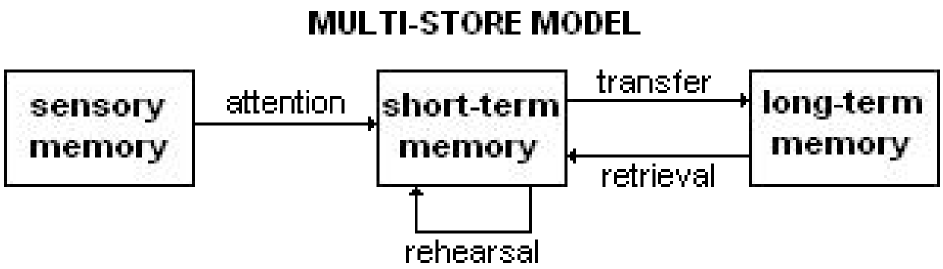

Figure 1.1 Multi-store model

In 1968, Atkinson and Shiffrin presented a multi-store model of memory. This model divides memory into three parts: (1) sensory memory, (2) short-term memory, and (3) long-term memory[2] (see Figure 1.1). In this model, information from outside is temporarily stored in short-term memory, and then, after processing, retained information is transferred to long-term memory. Atkinson and Shiffrin also noted that short-term memory is limited in capacity, and information is maintained in it through rehearsal. If not rehearsed, information is rapidly lost.[2] Accepted by most researchers, this conceptualization of short-term memory is widely used in explaining complex human cognitive system.

1.2 Working Memory

Despite a wealth of experiments supporting short-term memory and long-term memory can explain many human cognition phenomena, it soon demonstrated that short-term memory was overly simplistic. Although short-term memory is the initial conception of memory system, it couldn’t explain many higher human cognitive functions such as retrieval and reasoning.

In 1974, Alan Baddeley and Graham Hitch presented the concept of working memory as an alternative to the short-term memory.. Their theory includes a model that more accurately describes short-term memory. This working memory model is composed of three main components: (1) the central executive section, which acts as a supervisory system and controls the flow of information to and from its two slave systems; (2) the phonological loop, based on sound and language; and (3) the visuospatial sketchpad, based on vision and tactility (see Figure 1.2). The phonological loop stores verbal content whereas the visuospatial sketchpad stores visual or spatial information. Both slave systems function as short-term storage centers. In 2000, Baddeley added a third slave system, the episodic buffer, to the model. At the time, working memory model represented the dominant view in the field of memory system and human cognition system.

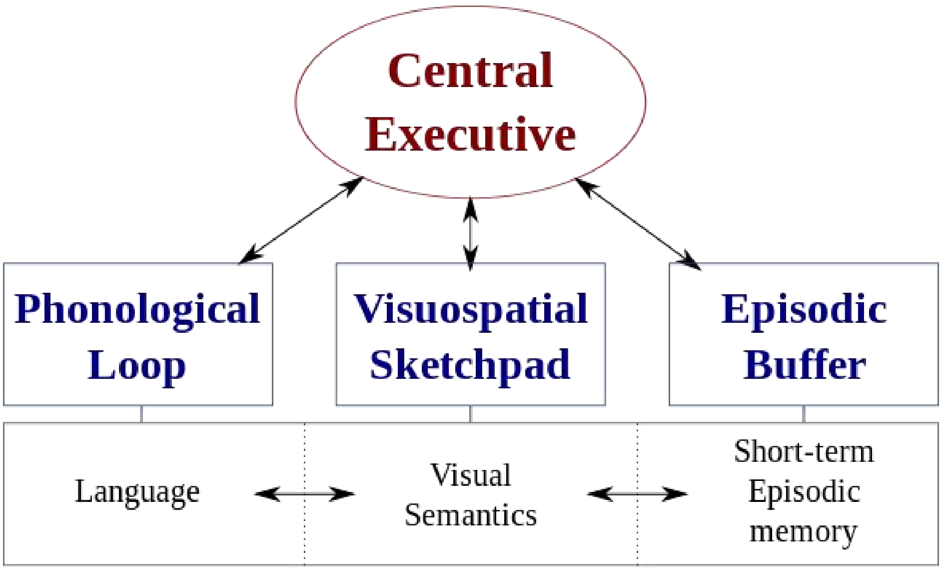

Figure 1.2 Working memory model

In the phonological loop part of working memory system, phonological and visual information about language, words, sentences, and paragraphs are all temporarily stored. However, the capabilities of the phonological loop are limited. For instance, while someone is reading a book or a newspaper, a great deal of information enters the phonological loop, but not of all the information needs to be analyzed. Most information is stored in the phonological loop and replaced with new information that comes in later. The visuospatial sketchpad is similar to the phonological loop, in that it also has limited capacity and temporarily stores objects' features such as color, location, and shape.

As mentioned above, the phonological loop and visuospatial sketchpad are used to store temporary verbal or visual information. While the information is temporarily stored, the central executive part filters out useful information for advanced processing and long-term storage. For instance, new information is classified and linked with existed memory in the central executive segment. In addition, through the recoding and linking procedure, new information can be stored for longer time and recalled easily. This information processing function is the main difference between the working memory system and the short-term memory system. Since the capacity of the central executive is limited, it cannot process lots of information during a period of time. This explains why people cannot remember amount of information in a short time. Also, there are many factors can effect the capacity of central executive, like the complexity of information. In this thesis, we studied the influence of attention on information processing function by comparing test result of simple and complex span test.

In conclusion, the concept of short-term memory only explains temporary information storage. The idea of working memory was introduced to explain that information can be both processed and stored in temporary memory.

1.3 Simple span test and complex span test

Based on the differences and similarities between short-term memory and working memory, many memory tests have been created, such as the digital span test. These tests can be divided into simple span tests and complex span tests.

The simple span test is used to measure participants' short-term memory capacity. In a simple span test, subjects are given a list of items that they need to remember and recall later. Depending on the type of tests, the items can be digits, letters, or words. Then subjects are asked to recall the list either immediately following presentation of the last item or after a short delay. The number of items correctly recalled is used to calculate participants' short-term memory capacity.

The complex span test is used to measure participants' working memory capacity. In a complex span test, subjects also need to remember a list of items to recall later. The difference between a complex and simple span test is that in a complex span test participants engage in some other processing activity unrelated to the current memory task. This activity interferes in the presentation of the items subjects need to remember. The result-calculation method of the complex span test is similar to that used for the simple span test.

Many studies have been undertaken in order to find the differences and similarities between these two kinds of tests. Most of the results support better correlation between the complex span test and human cognitive abilities than between the simple span test and human cognitive abilities. However, most of these studies focus on the features of to-be-remembered items in the tests. Since it has been proven that a participant's mental condition can affect his or her memory test results, this thesis discusses the correlation between attention and memory test results during simple and complex span tests.

1.4 Attention

Attention refers to the processing or selecting of some information at the expense of other information.[22] There is evidence that attention can affect early perceptual processing, as well as evidence that attention affects only later processing stages.[23] The strong support for both early and late selection has led to the suggestion that there may be more than one form of attention. According to recent studies, there are three attention networks which perform distinct roles: alert, orient, and executive attention. The alerting network controls the general state of responsiveness to sensory stimulation. The orienting network selects a subset of sensory information for privileged processing. The executive attention network acts on post-sensory representations, and is needed when there is competition for access to the central, limited-capacity system.[1] Since each of attention network plays leading roles in different mental states, it is difficult to determine the specific attention network and the way it affects human memory system. There are, however, methods for measuring human cognitive conditions using EEG, for example, to see if a subject is focusing on particular signals or information.

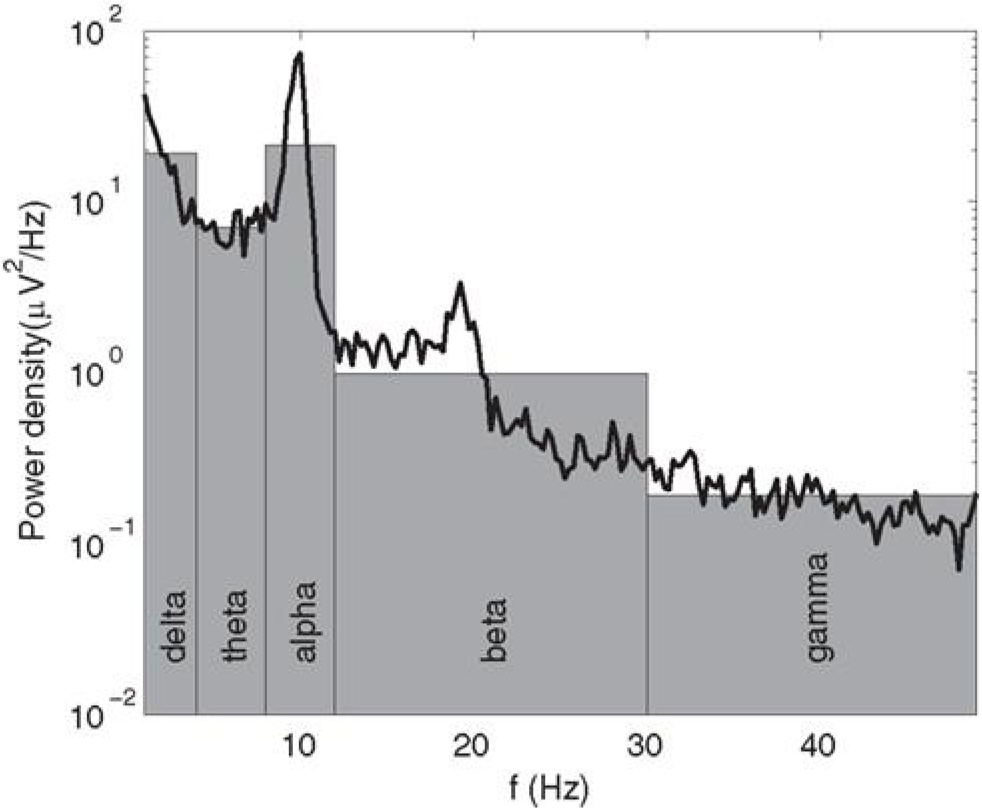

Figure 1.3. EEG spectrum (black line) with its EEG approximation in terms of band powers, given by the areas of the gray bars.

Through Fourier transform, the electric signals from electrodes are shown as a graph with frequency-domain (see Figure 1.3). Academics have divided the electroencephalograph into five parts based on the relevant mental states (see Table 1). The alpha and beta bands are the dominant parts of electroencephalograph band during conscious state. In addition, the band of 8 Hz to 31 Hz can be used to study human cognitive behavior.

Table1.1 EEG frequency bands and relevant brain states

EEG Level	Frequency band region	Mental states
Delta(δ)	0.1Hz to 3Hz	Unconsciousness (deep, dreamless sleep)
Theta(θ)	4Hz to 7Hz	Catnap (intuitive, dream, recall, imaginary)
Alpha(α)	8Hz to 12Hz	Relaxation (meditation)
Beta(β)	12Hz to 30Hz	Focusing/Stress (alertness, thinking, aware of self and surroundings)

Research completed by Monina Islarm determined that an EEG can be used to build a model for emotions. In his experiment, the alpha band is active during a simple workload. When workload or pressure on the human brain increases, such as during problem-solving tasks, the beta band is active.[24] This means when subjects need to exert more attention on the experiment task, the power density of the beta band will increase. Then Mathematical models for relaxed (low-attention state) and focused states (high-attention state) are constructed based on the alpha and beta frequency band, respectively.

Some studies with EEGs have begun to elucidate how attention-control mechanisms might affect information recoding (one of information processing function in working memory system) and how, in turn, such control and orienting might be modulated by past experience (the retrieval of information from long-term memory).[25] For instance, one experiment has demonstrated that knowledge about the location that visual stimuli will appear in (hemifield) can affect positive and negative deflections of EEG signals at around 100 ms post-stimulus onset,[26] revealing the effect of perceptual attention at an early sensory processing stage.[27] Attention can also affect EEG signals associated with later central processing stages, such as those involved in the selection and initiation of responses.[23]

In conclusion, EEG can be used to examine the mental state of individuals, so using EEG to reflect the degree of subject's focus state could be reliable. In this thesis, we recorded subjects' mental state in different memory span tests to find the correlation between their mental state conditions and their test results. Also, we assumed that a high-focus state of subjects could improve their test results.

1.4 NeuroSky MindWave headset

In general, an EEG is obtained by placing electrodes on the scalp. The electrodes are placed in accordance with the 10-20 international system (see Figure 1.4) and fixed with a conductive gel. The amplitude of the voltage between two electrodes is typically between 1 and 100uV and may be higher when needle electrodes are used.

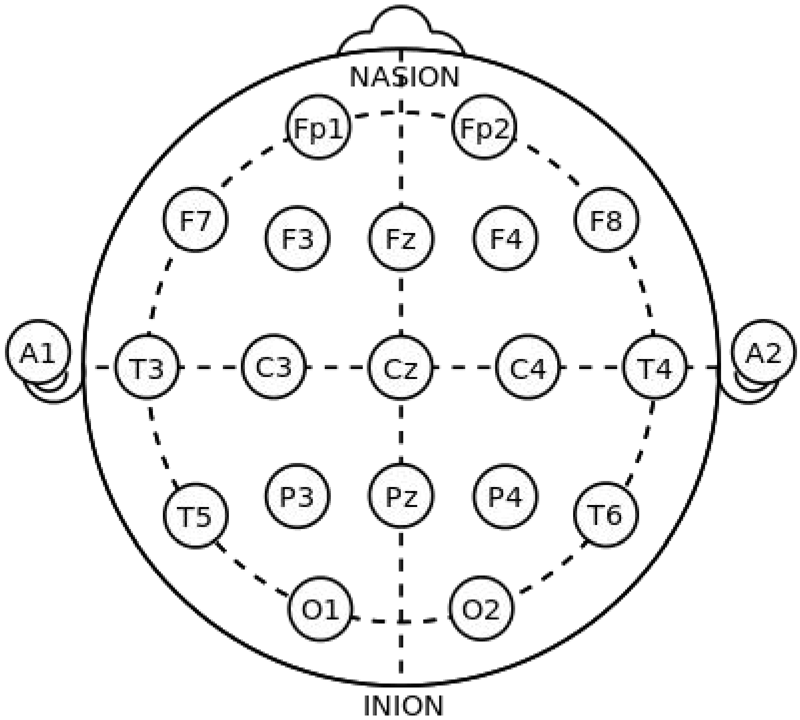

Figure 1.4 10-20 international system

After collecting signals from the electrodes, the difference of the voltage between two electrodes is recorded and processed using Fast Fourier Transform. The spectrum of the EEG can then be presented in the frequency-domain (see Figure 1.5). The EEG spectrum over a period of time can then be observed and divided by range of frequency. EEG experiments increasingly analyze the relation between frequency bands and mental state. Researchers have found a frequency ranging from 0–30 Hz while EEG is recorded from a subject under different conditions. The the frequency spectrum is then divided into four frequency bands, delta, theta, alpha, and beta, based on different mental states (see Table 1.1). As discussed, some experiments have shown that the power density of the beta band can be used to explore focused or high-attention states.

The NeuroSky MindWave headset, launched in 2010/2011, was designed to identify and monitor electric signals generated by neural activity in the brain. It consists of a headband, an ear clip, and a sensor arm containing the EEG electrode which rests on the forehead above the eye (FP1 position; see Figure 1.6). The NeuroSky MindWave headset measures (1) the raw signal, (2) the EEG power spectrum, and (3) the information of EEG frequency bands. From the raw signal, the headset can give two eSense metrics: attention and meditation. Using the EEG signals from electrodes, the eSense metrics provided by the NeuroSky MindWave headset can be monitored at a rate of 1 Hz. These eSense metrics are used to determine how effectively the user is paying attention (similar to concentration) or meditating (similar to relaxation) by decoding electrical signals and applying algorithms to provide a reading on a scale of 0–100 (see Figure 1.7). Distractions, wandering thoughts, lack of focus, or anxiety may lower the attention level.[28;29]

Table 1.2 Descriptions of eSense metrics values

Value	Description
1-20	'Strongly lowered' levels
20-40	'Reduced' levels
40-60	'Neutral' / 'Baseline' levels
60-80	'Slightly elevated' / higher than normal levels
80-100	'Elevated' / heightened levels

Although the clinical EEG monitor is more accurate in measuring EEG signal, the operation and preparation of a clinical EEG monitor is a time-consuming and complex process, as placing electrodes around the head and attaching them with conductive gel often takes 30 minutes or more. In addition, the process must be supervised and performed by a trained individual. The NeuroSky MindWave headset, by contrast, provides cheaper, wireless, portable, non-invasive, noise-resistant and simpler operation. The sensors used by NeuroSky MindWave headset require no gel or saline for recording, and no expertise is required for setup.[29] Furthermore, a study by Mostow et al. notes, “even with the limitation of recording from only a single sensor and working with untrained users, the MindWave distinguished two fairly similar mental states (neutral and attentive) with accuracy.[30]

The NeuroSky MindWave provides raw EEG signal based on user's brainwaves (delta, theta, alpha, and beta) to determine levels of attention and meditation. Then these raw data are processed by a chip called ThinkGear in the NeuroSky MindWave headset which can also amplify the raw brainwave signal and remove ambient noise and artifacts.[29] Because the original code of ThinkGear is unpublished, we designed some simple tests to determine how can the attention level given by NeuroSky MindWave reflect a subject’s mental state. In these simple tests, we studied the output signals of NeuroSky MindWave from a participant while meditating, reading and solving a mathematical problem (see Figure 1.5). The participant was asked to solve the mathematical problem in one minute. However, we didn’t place any time restrictions on the other two tasks. We supposed that the participant would pay more attention to the mathematical problem and the NeuroSky MindWave would give a higher value of ‘attention’ in the same task. From the result, we found that the participant got the highest ‘attention’ value while solving the mathematical problem and lowest ‘attention’ value during meditation. This finding supported the contention that NeuroSky MindWave could be used to measure the degree of subject’s focus state and express it as attention level.

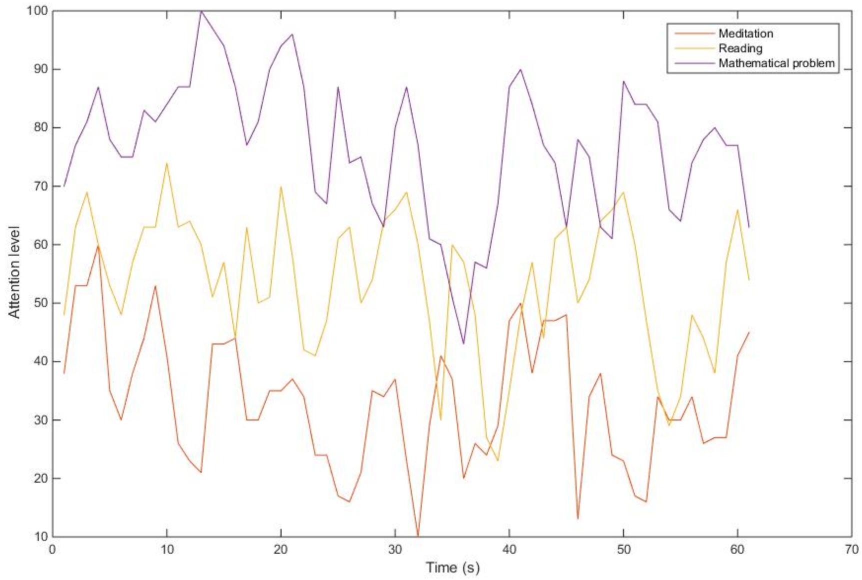

Figure 1.5 Subject's Attention level from NeuroSky MindWave while meditation, reading and solving mathematical problem

In this thesis, we used NeuroSky MindWave to collect data about subjects' attention level while taking different memory span tests. Though these data, we could find the correlation between subjects' memory span test results and the attention level which is given by the NeuroSky MindWave headset. After that, by using the ThinkGear module on the development platform, we designed an application which can estimate users' capacities for short-term memory and working memory.

Objective

This study aims to record subject's attention level during various memory span tests by using NeuroSky MindWave headset. Then we can determine the correlations between attention level and test results. At last, our study will compare the differences in these correlations for different memory span tests to determine the influence of attention in these memory span test. The results can help us find out a new orientation of measuring participant's memory capacity by using a wireless EEG system.

Hypothesis

When an individual is completing a simple span test, the attention level recorded by the NeuroSky MindWave headset will correlate with the result of the test. This study hypothesizes that there has positive correlation between attention level and test score in both simple and complex span test. Moreover, when an individual completes a simple span test, the individual's attention level will be lower than while completing a complex span test because the complex span test requires participants to pay more attention in the test.

Chapter 2

Methods

2.1 Participants

Participants were 10 native Chinese speakers (1 female, 10 male) at who are students at Florida Institute of Technology. They were paid a small fee for their participation. All subjects had normal vision and normal hearing, and all were right-handed. None of the subjects had any neurological impairment, nor were they trained before the test.

2.2 Instruments

NeuroSky MindWave headset; a projector (to display the memory span tests); memory span test forms and pencils (to record the results of the memory tests).

2.3 Materials

2.3.1 Digit span test materials

Short-term memory is involved in many everyday memory tasks, from remembering a telephone number to understanding a long and difficult sentence. Therefore in the simple span tests, the digit span task is a main component of short-term memory measurement.

The digit span test was conducted as follows: A series of numbers was presented at a rate of one digit per second. When subjects were told that the test began, they had to type all of the numbers onto the keyboard in the sequence in which they occurred. If the subject correctly remembered all of the numbers, then the next list of numbers would be one number longer. If the subject made a mistake, then the next list of numbers would be one number shorter. The subjects had three chances to continue when they made a mistake. The final score of this test would be the maximum number of digits successfully reached. The result would be recorded as the subject's DS (digit span) score, which was used to determine the variable ‘Preload’ for word span test and subject’s capacity of short-term memory.

2.3.2 Word span test

Word span test is also used in measuring subject’s short-term memory ability. Because word span test is not involved subject’s reasoning skill and retrieval processing, it is also regarded as a kind of simple span test for short-term memory. In this thesis, we used four parallel forms of the word span test were constructed as follows: 80 high-frequency and unrelated words ranging from two to three syllables in length were chosen from SAT reading tests. These words were then randomly assigned to four lists, each with 12 two-syllable words and four three-syllable words. In each trial, a list of words was presented at a rate of one word every two seconds. There were some differences between the word span tests in each trial. The tests taken in the different trials were: 1) word span test presented visually without preload, 2) word span test presented visually with preload. (The test with preload can be regard as a more difficult word span test)

The procedure for each word span test was as follows: For the tests presented visually, a projector was used to display the word list for participants. In the tests with preload, a sequence of numbers was given by the experimenter as the preload. The length of the preload was determined by each subject's digit span score, and the digits of the preload were generated by a random sequence generator. Before the tests with preload, the experimenter instructed participants to continue reviewing the preload during the word span test and write it down once the word presentation was finished. For this task, participants were given 20 seconds to practice before the word span test. After each test, participants were required to write down as many words as possible in one minute. Their answers were written on the word span test form and the number of correctly remembered words was recorded. The proportion of words recalled was calculated for each trial and transformed to a score from 0 to 100 (e.g. if a participant recalled 12 out of 16 words in a trial, he or she scored 75 for that trial).

2.3.3 Reading span test

The reading span test is a kind of complex memory span test. It is used to measure subjects' short-term memory, cognitive processing ability and reading comprehension ability. In addition, subjects need to store and process the information simultaneously in the reading span test rather than just store information in the digit span test and word span test. So this test can give a more reliable assessment of subjects' working memory capacity.

The reading span test was conducted as follows: Sentences were chosen from SAT reading tests for a total of 80 sentences ranging in length from 15 to 20 words each. The last word in each sentence had the same length and number of syllables, and was not repeated in any other sentence. Of all 80 sentences, 42 sentences were randomly assigned to the reading span test. The test was divided into four parts: Level 2, Level 3, Level 4, and Level 5. At each level, there were three trials containing sentences used for the test. The number of sentences was determined by the degree of the level (e.g. at Level 2 there were three trials containing two sentences each, and at Level 5 there were three trials containing five sentences each), for a total of 12 trials in the test. Before beginning the test, subjects completed a practice trial at Level 2, which consisted of the last two sentences from this level.[31;32]

The procedure for the reading span test was as follows: The participants were instructed to read the sentences in each trial either silently (in which case subjects gave the experimenter a signal as they finished reading) or out loud. Once the subjects finished reading, the experimenter provided the next sentence after one second. The participants were instructed to recall the last word of each sentence in the trial after every sentence was displayed. The experimenter also emphasized the importance of reading the whole sentence rather than just a few words, and reminded the participants of this when they paused. After each trial, a notice asking participants to recall the last word of the sentence presented before was displayed on the screen in blue text, in order to distinguish from the trial sentences. Once subjects finished the recall period, the experimenter continued the next trial at this level. The proportion of words recalled was calculated for each level and transformed to a score from 0 to 1.00 (e.g. if a participant recalled five out of six words in a trial, he or she scored 0.83 at that level).

2.4 Experiment Procedure

1.Participants take the digit span test. Their scores for the digit span test are recorded.

2.Participants wear the NeuroSky MindWave headset as instructed by the experimenter. Output data (attention level) must be recorded for 60 seconds to check the working condition of the headset. Each participant is asked to read a paragraph during this period. If the output can be read normally, the experimenter may proceed to the next step. If not, the experimenter should check whether the electrodes are touching the participant’s skin.

3.The two forms of the word span test are given to the participants, along with test answer forms and pencils.

4.Participants begin the two forms of the word span test as described in the procedure above. The experimenter records the attention level provided by the NeuroSky MindWave headset during each test.

5.Participants' test answer forms are collected and their word span scores are calculated. Participants may have a break before the next test.

6.The reading span test is given to participants, along with a new test answer form.

7.Participants begin the reading span test as described in the procedure above. The experimenter records the attention level provided by the NeuroSky MindWave headset during each test.

8.The experimenter helps participants take off the device and thanks them for their participation. Participants are now free to leave. The experimenter collects participants' test answer forms and calculates their reading span scores. Participants may know their scores for each test if they wish.

9.The experimenter analyzes the recorded data provided by the NeuroSky MindWave headset for each test, as well as each participant's test scores.

2.5 Data classification

This section describes the analysis of the attention level data given by the NeuroSky MindWave headset and participants' test results. The data from the word span tests were divided into two groups (digit span 9 and digit span 10) according to participants' different digit span scores and the different forms of word span tests. The data from the reading span tests were divided into 10 groups according to different participants and test levels.

The reason for such classification is as follows: The word span test and digit span test are widely used in short-term memory test (simple span test). As we mentioned above, the simple memory span test is used to measure participants' short-term memory (storage capacity). Therefore, the results of digit span test and word span test could have some correlation for they both measuring subject's short-term memory (storage capacity). And when we analyzed participants' scores on these two tests, it was obvious that participants who earned a high digit span score (such as a 10) were able to recall more words in the word span test. So we divided subjects into 2 groups (digit score as 9 and digit score as 10) based on their digit span test results. In each groups, we used data of attention level from NeuroSky MindWave and subjects' word span test results to build a scatter plot.

The reading span test is used to measure not only the storage capacity of the memory system, but also its processing capacity. In addition, this test simulates our daily studying and working conditions, which involves saving and processing information at the same time. So we divided the data from reading span test into 4 groups based on the level of trails. In each group, we also divided subjects into 2 groups as the method used in processing word span test. Also we used the each subject's attention level and test score in whole reading span test to find the correlation.

From the word span test, we observed that all participants' mean attention levels increased when they earned higher test scores or took a more difficult test. But when they were taking reading span test, each participant's mean attention level range for different level tests was quite distinct. For reading span test is a kind of complex span test, multiple working memory activities (like processing information and storage of information) occur simultaneously during the period of remembering activity, participants' attention could be divided toward other work (such as paying more attention to processing information than saving the information that is continuously brought into memory). And each participant could pay different degree of attention on remembering work based on his reading habit and individual differences. Since complex span test is testing two functions of memory system, this can be an interfere to our measurement of attention. However, the data from word span test had shown that the correlation between attention level and test results was exist. This result both approved our hypothesis and the reliability of data from NeuroSky MindWave headset. Through the reasons mentioned above, we assumed this condition was probably caused by participants' individual differences and their different reading habits in the sense that some focused on what they were reading, while others focused on classifying and repeating the information they needed rather than paying attention to reading. So we decided to process subjects' reading span test results respectively with their simple span test results and their attention level during each test.

After classifying the data, we used least squares regression to first determine whether there was a positive or negative correlation between attention level and test scores in each group, then develop a formula to describe the correlation between subjects' attention level and their test scores.

Chapter 3

Results

3.1 Simple span test

In the word span test, there are two trials: Word span test presented visually without preload; Word span test presented visually with preload.

Table 3.1 Mean attention level of subject and their test score in word span test presented visually without preload

Digit span score = 9			Digit span score = 10		
Attention level		Test score	Attention level		Test score
M	SD		M	SD	
34.471	12.768	31.25	41.25	20.144	43.75
41.471	15.866	43.75	55.853	9.487	43.75
65.857	15.928	50	57.273	15.101	43.75
72.571	15.714	62.5	60.139	18.264	50
74.471	16.516	56.25	62.722	19.115	75

Note: M is mean value of attention level during test; SD is standard deviation.

Table 3.2 Mean attention level of subject and their test score in word span test presented visually with preload

Digit span score = 9			Digit span score = 10		
Attention level		Test score	Attention level		Test score
Mean	SD		Mean	SD	
48.139	9.123	18.75	48.530	11.128	18.75
49.743	15.863	6.25	52.324	15.731	50
55.25	19.497	37.5	55.667	13.011	31.25
59.529	19.458	31.25	63.057	21.710	31.25
60.412	9.493	56.25	66.029	28.373	43.75

Note: M is mean value of attention level during test; SD is standard deviation.

From the table above, we found that:

1. In word span test without preload. Participants got higher test scores while they had higher attention level. Also, subject who got higher digit span score could get a higher test score in this test.

2. In word span test with preload. The result also showed that participants could get higher test score in high attention level. Also, we found that the interference had greater negative effect on subject who got higher digit span score.

These result support our hypothesis that there is a positive correlation between attention level and simple span test score. Also, we found that additional interference could divide subject's attention and cause a decrease on their test scores. Based on the test results, we built a scatter plot and processed the data by using least squares regression. The graph of the correlation between attention level and test score in different word span trial is displayed below the table.

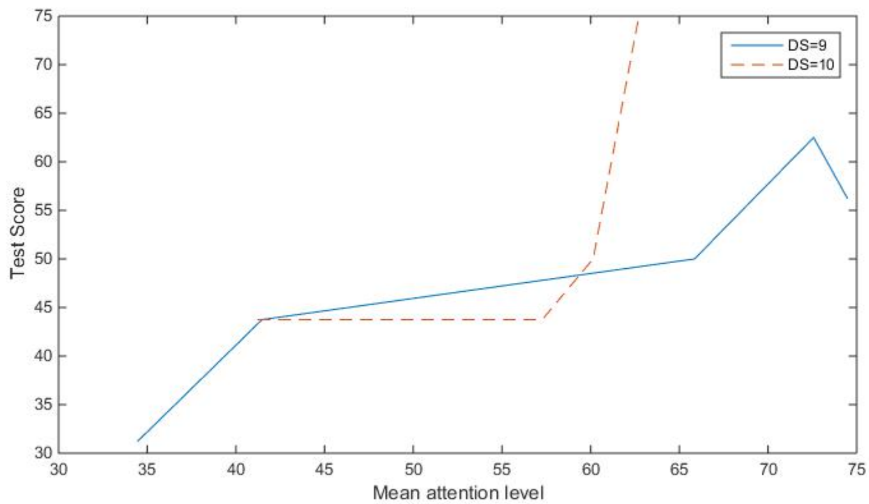

Figure 3.1 The run chart of attention level and test score for participants in word span test without preload.

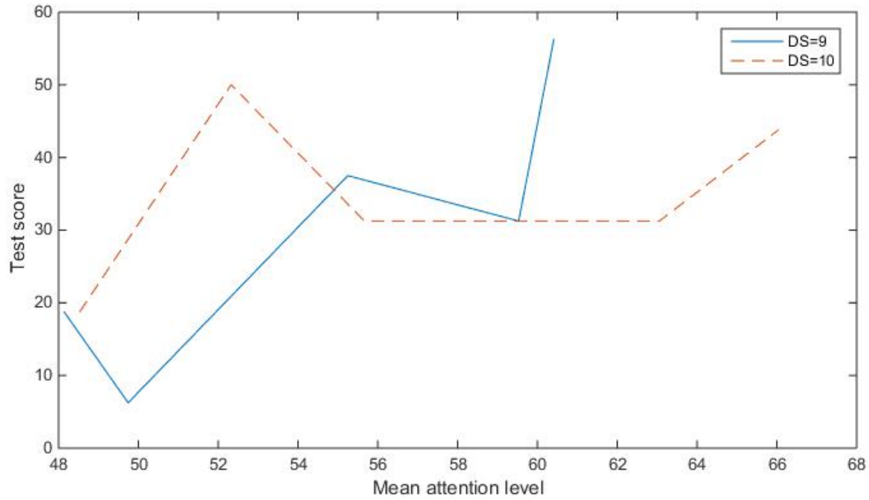

Figure 3.2 The run chart of attention level and test score for participants in word span test with preload.

From the figures and data above, we found that most data groups showed a positive correlation between subject's attention level and their test scores. However, in word span test with preload, two subjects' data were abnormal. This could be caused by the additional interference in word span test with preload. The preload could make participants pay more attention to the repeating the additional interference information rather than focusing their attention on the word list. So we didn't use these two subjects' data when processed the result through least squares regression and multiple regression.

Table 3.3 Correlations among participant's mean attention level and test score in different word span test

	DS=9	DS=10	Whole data
Presented visually without preload	TS=0.6×A+14	TS=0.92×A+0.42	TS=0.657×A+4.024×DS－25.401
Presented visually with preload	TS=0.6×A+0.55	TS=2.2×A－87	TS=1.091×A－2.343×DS－3.897

Note: TS is test score; A is mean attention level; DS is subject's digit span score.

Though the equations based on our result of experiment, we found there always had positive correlation between mean attention level and test score in each equation. This approved that attention level performed by NeuroSky MindWave headset can be used as a measurement of wearer's storage capacity of working memory system.

3.2 Complex span test

In the reading span test, there are 4 different level trails.

Table 3.4 Attention level and test score of each level trail and the whole test in the reading span test

		DS=9					DS=10				
Trail level 1	M	30.8	38.6	60.5	67.8	72.1	27.8	46.7	55.3	59.0	65.6
	SD	16.8	18.6	21.3	17.2	17.0	15.6	13.4	23.4	22.2	26.0
	TS	100	100	100	100	100	100	100	100	83.4	100
Trail level 2	M	39.5	47.1	71.1	61.7	55.7	33.1	36.1	58.4	42.2	50.8
	SD	12.8	16.5	15.7	11.7	11.5	17.9	18.2	18.7	18.8	14.7
	TS	88.9	88.9	88.9	100	100	100	100	100	88.9	88.9
Trail level 3	M	35.7	40.0	62.7	63.7	46.9	34.2	54.3	53.8	55.0	37.1
	SD	12.9	16.7	16.8	12.3	13.1	11.6	13.9	18.1	18.0	20.0
	TS	100	83.3	83.3	91.7	91.7	100	66.7	75	83.3	66.7
Trail level 4	M	32.9	43.3	51.9	51.9	50.8	54.9	37.1	62.6	54.1	49.9
	SD	14.6	16.1	15.1	16.8	14.4	16.9	21.6	18.3	18.3	17.8
	TS	53.3	66.7	80	86.7	73.3	40	40	53.3	46.7	40
All trials of RST	M	34.7	42.4	60.8	59.8	53.5	39.8	43.8	57.8	52.4	48.8
	SD	14.4	17.0	18.2	16.0	15.9	19.1	19.2	19.4	19.8	20.8
	TS	80.9	80.9	85.7	92.9	88.1	78.6	69.0	76.2	74.4	66.7

Note: DS is subject's digit span score; M is mean attention level of each trail and whole test; SD is standard deviation; TS is test score.

From the data above, we found:

1.Subject's test score was decreased while taking higher level trails. This approved that the capacity of working memory is limited. So subjects had troubles when took a more complex memory task in reading span test.

2.Most Subject's mean attention level of each level trail didn't show a high positive variation trend.

For the second point, we considered this phenomena was caused by the different measure methods between simple span test and complex span test. So we compared the result of word span test and reading span test to find the relation between them.

Table 3.5 Comparison of simple span test result and complex span test result

	RST		WST without preload		WST with prelaod	
	Mean Attention	TS	Mean Attention	TS	Mean Attention	TS
DS=9	34.705	80.952	41.471	48.75	48.139	18.75
	42.441	80.952	34.471	31.25	55.25	37.5
	53.531	88.952	72.571	62.25	49.743	6.25
	59.849	92.857	65.857	50	59.529	31.25
	60.768	85.714	74.471	56.25	60.412	56.25
DS=10	39.832	78.571	41.25	43.75	48.529	18.75
	43.791	69.048	62.722	75	63.057	31.25
	48.849	66.667	60.139	50	52.324	50
	52.442	74.429	57.273	43.75	55.667	31.25
	57.804	76.19	55.853	43.75	66.029	43.75

Note: RST is reading span test; WST is word span test; Mean Attention is the mean value of attention level during the whole test; TS is test score; DS is digit span score.

From the compassion of reading span test and word span test, we found:

1. Most subject showed higher mean attention level during span simple test. We assumed this phenomena was caused of multiple information processing in complex span test.

2. In whole reading span test. Our data showed a lower positive correlation between attention level and test score. But in simple span test showed above, we found a higher positive correlation between attention level and test score was confirmed.

3. In high level trail (level 5 trail) of reading span test. We found a high positive correlation between attention level and test score.

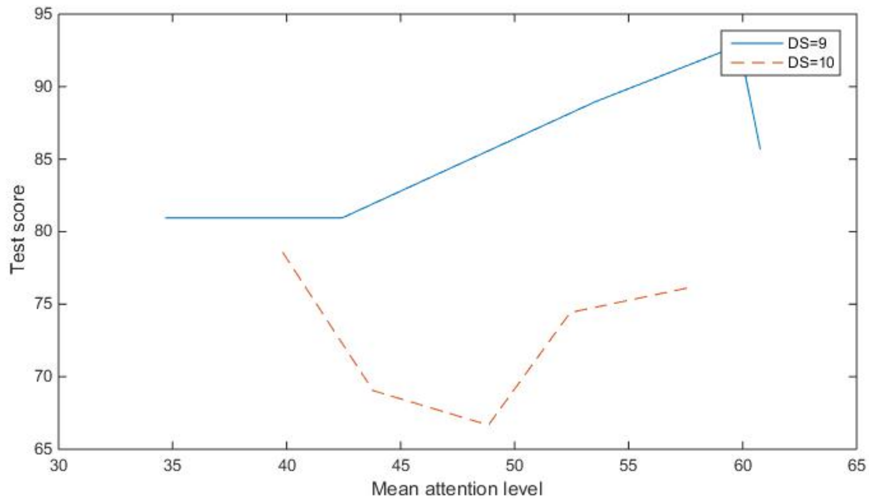

Figure 3.3 The run chart of attention level and test score for participants in reading span test.

Table 3.6 Correlations among participant's mean attention level and test score in reading span test

	DS=9	DS=10	Whole data
Reading span test	TS=67+0.37×A	TS=72+0.017×A	TS=184.233－0.271×A－12.440×DS

Note: TS is test score; A is mean attention level; DS is subject's digit span score.

Since simple span test is mainly used to measure subject's short-term memory (information storage function), complex span test is mainly used to measure working memory (information storage and processing function). The lower correlation between attention level and test score in the complex span test could be explained as the participants paid attention to what they were reading (information processing function of working memory system), it would interfere with their information storage function.

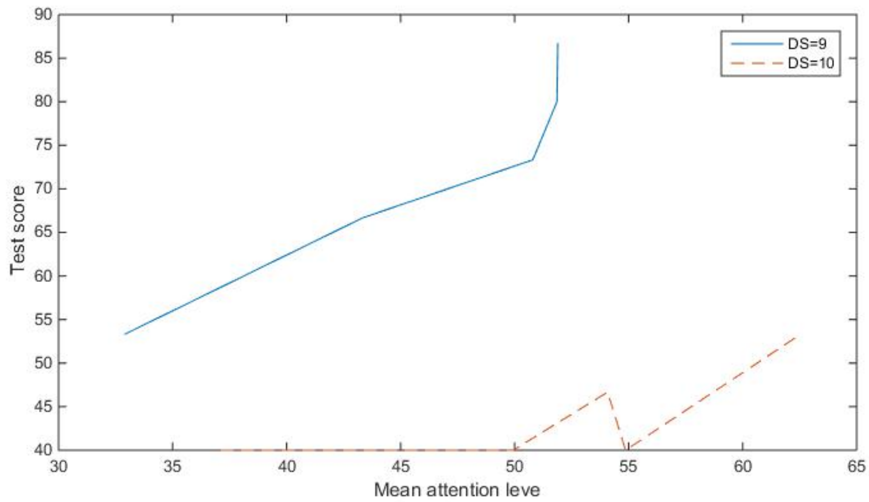

Figure 3.4 The run chart of attention level and test score for subjects in level 5 trail of reading span test.

In level 5 trail of reading span test. We also found high positive correlation between attention level and test score. And this correlation got higher when the test level increased. This supports the opinion that subject's focus state become important while taking difficult memory task. In the simple span test, the correlation between attention and test score also showed higher when subject took preload test. So we considered subject's focus state played an important role in high difficulty simple and complex span tests.

Chapter 4

Conclusion

This chapter discusses first the main results by comparing the word span and reading span tests, then highlights the contributions of the study and poses questions for future work.

4.1 Discussion of results

Though comparing the results of simple span test and complex span test, we determined the effect of attention on these two different memory span test. The result of our study showed that NeuroSky MindWave headset provided a higher correlation between attention and test score in simple span test. Since the simple test (word span test) is only used to measure subject's short-term memory (information storage function) and complex span test (reading span test) is widely used in measuring working memory (both information processing and storage functions). We pointed that:

1. The focus state of human plays more important role while taking simple information storage task. Furthermore, the information storage capacity is enhanced when people got higher focus state.

2. The attention level given by the NeuroSky MindWave headset could be used to reflect the wearer's capacity of short-term memory in the simple span test. But for complex span test, the attention level can not reflect both the information storage and processing function of memory system well.

Because of the higher correlation between attention and test score in simple span test. We designed an application that can score user's capacity of short-term memory while working on simple memory task. The application is designed as follows:

(1) A project was built to transport the output data (attention level) from the NeuroSky MindWave headset by using the NeuroSky Developer Kit on Android Studio.

(2) Then the attention level data was recorded for a period of time and averaged to get the mean attention level during this period.

(3) The value of mean attention level and user's digit span score were entered in the arithmetic formula:

$$\mathbf{TS = 1.091 \times A - 2.343 \times DS - 3.897}$$

Which TS is the score of user's short-term memory capacity; A is mean attention level; DS is user's digit span score. Then we could easily measure NeuroSky MindWave user's short-term memory.

4.2 Contributions

This thesis makes three contributions. First, it compared the influence of focus state in simple memory span test and complex memory span test. Second, it presented that attention plays a more important role in measuring short-term memory. Third, our study gave a sample application using a wireless EEG system to measure user's short-term memory capacity. Overall, this thesis confirms the assumption that there is a positive correlation between attention and memory test result.

4.3 Future work

Although this experiment confirms the positive correlation between attention and memory test result, there are still some problems in using NeuroSky MindWave headset to measure user's working memory capacity.

1. NeuroSky MindWave's original code which used to transfer raw EEG signal to eSense data is not clear. So a further study to determine the relationship between raw EEG signal and attention level given by NeuroSky MindWave would be important.

2. In complex span test, we found low correlation between attention and test score. For information storage and processing function are both performing in the complex span test. We assumed the attention had low correlation with the information processing function. Then we observed low correlation between attention and test score in complex span test rather then simple span test. But we still need more subjects to support our hypothesis.

3. The improvement of our short-term memory application on smart cell phone is necessary. Because current application could only measure user’s short-term memory capacity while taking simple memory task. Since the wireless EEG system is easy to use, our future work will focus on measure user’s short-term memory during different condition.

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