A Study on Forward and Backward Digit Span Test

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Declaration

I hereby declare and confirm that this study, titled **"A Study on Forward and Backward Digit Span Test"** is an outcome of my own efforts under the guidance of Dr. Debdulal Dutta Roy (Head & Associate Professor, Psychology Research Unit, Indian Statistical Institute, Kolkata). All sources used in this paper have been properly cited and referenced, and this work is free from any form of plagiarism, including self-plagiarism. All the data used in the study has been collected by myself.

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Contents

1 Introduction

1.1 Importance to Study:

In the field of Psychology, the study of digit span is a crucial way of quantifying short-term memory. Through this test, a researcher can assess the short-term memory capacity on the basis of which, the researcher can judge how much the subject is capable of remembering a small amount of information that lasts less than 30 seconds, i.e. short-term memory.

1.2 General Problem:

In this practical, the general problem is to study memory. Particularly we will study short-term memory here, i.e. the capacity of a person to hold a small amount of information in mind in an active, readily available state for a short period of time.

1.3 Specific Problem:

We are interested here to determine short-term memory span using a customized Forward Digit Span Test of a few selected subjects on the basis of age, gender, educational qualifications, etc.

1.4 Introduction to Study Variables

We will be studying the data of forward and backward digit span from different age groups, gender, qualification, etc.

1. **Forward Digit Span:** Quantifies short-term memory capacity
2. **Backward Digit Span:** Quantifies working memory capacity
3. **Age, Sex and Educational Level:**
    - **Age:** Age is an important covariate when studying short-term memory because cognitive abilities often decline with age. As we collect data from participants of different ages, we will control for any age-related differences in short-term memory performance and a better understanding of how other factors such as gender and education impact memory performance.
    - **Gender:** Gender is another important covariate to consider when studying short-term memory because research has shown that there are often gender differences in memory performance. By including gender as a covariate in our analysis, we can control for any gender-related differences in memory performance and better understand how other factors such as age and education impact memory performance.
    - **Educational Level:** Education is an important covariate to consider when studying short-term memory because education is often associated with cognitive abilities. People with higher levels of education tend to have better working memory capacity and may be better able to remember information in the short term. We will collect

data on educational level and use this information to control for any educational-related differences in short-term memory performance and a better understanding of how other factors such as age and gender impact memory performance. For Educational Level, Level 1 is under or at 10, Level 2 is under or at 12 and above 10, and Level 3 is after 12.

1.5 Objectives and rationalization

The problem which we are concerned about is to study **memory**, in fact, short-term memory and working memory to be precise. Since memory is an abstract object, so we try to qualify a person's memory capacity in various ways. One of these ways is called the **Digit Span test.**

The objective of this study is to determine the **Memory Span** or the **Digit Span** of a few selected subjects. Afterward, we may use our collected data to comment on the short-term memory of the subjects on the basis of age, gender, educational qualification, etc.
Digit span is a psychological test used to assess an individual's working memory capacity. The main objective of digit span is to measure an individual's ability to recall a series of digits, either in the same order they were presented or in reverse order. The test is used to assess short-term memory capacity, attention, and concentration.
The digit span test is often used in clinical settings to diagnose and evaluate cognitive impairments, such as those associated with Alzheimer's disease, traumatic brain injury, and other neurological disorders. It can also be used to assess the impact of interventions aimed at improving working memory and attention.
Overall, the objectives of the digit span test are to:

- Measure an individual's working memory capacity
- Assess attention and concentration skills
- Monitor changes in working memory capacity over time
- Evaluate the effectiveness of interventions aimed at improving working memory and attention.
- See and understand the effect of age, educational level, sex, etc. over forward and backward digit span.

1.6 Operational definitions of study variables

Digit Span is a measure or quantification of verbal short-term memory, defined as the system that allows a person for the temporary storage of information, and is very crucial in everyday tasks like remembering a telephone number and understanding long sentences.

In other words, memory span is the list of items that a person can remember and repeat back in correct or reverse order immediately after the presentation of 50% of the trials. So, memory span indicates how much information one can memorize for a short period of time. The items may include words, numbers, or letters. In particular, when numbers are used to administer the test, we call this task a digit span test.

1.7 Hypothetical model: Multi-Score Model of Memory

The multi-store model of memory (also known as the modal model) was proposed by Richard Atkinson and Richard Shiffrin (1968) and is a structural model. According to the model, memory consists of three states: a sensory register, short-term memory (STM), and long-term memory (LTM). Information enters the memory from the senses and is forgotten after a short period of time. A sight or sound that we might find interesting captures our attention, and our contemplation of this information - known as a rehearsal - leads to the data being promoted to the long-term memory, where it will be held for a few hours or even days in case we need access to it. Short-term memory gives us access to information that is salient to our current situation but is limited in its capacity. Therefore, we need to further rehearse information in short-term memory to remember it for longer. This may involve merely recalling and thinking about a past event or remembering a fact by rote - by thinking or writing about it repeatedly. Rehearsal then further promotes this significant information to the long-term memory store, where Atkinson and Shiffrin believed that it could survive for years, decades, or even a lifetime.

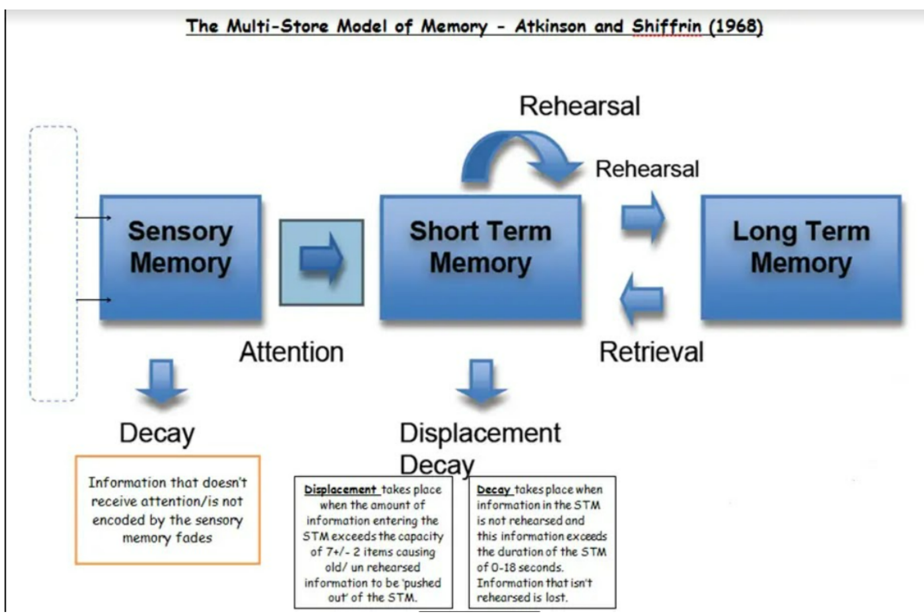

Figure 1: Multi-Store Model of Memory

1.8 Literature Review

Here are some examples of literature research work regarding digit span:

1.8.1 Development and Validation of Digit Span Memory Tests:

- Wechsler, D. (1997). WAIS-III: Wechsler Adult Intelligence Scale. Psychological Corporation.
- The WAIS-III is a widely used intelligence test that includes a digit span subtest. The test assesses both forward and backward digit span, as well as other aspects of verbal and nonverbal intelligence. The test has been validated in numerous studies and is considered a reliable and valid measure of cognitive ability.

1.8.2 Digit Span Memory Tests and Attention Deficit Hyperactivity Disorder(ADHD):

- Martinussen, R., and Tannock, R. (2006). Working memory impairments in children with attention-deficit hyperactivity disorder with and without comorbid language learning disorders. Journal of Clinical and Experimental Neuropsychology, 28(7), 1073-1094.
- This study investigates the relationship between digit span memory tests and attention deficit hyperactivity disorder (ADHD) with and without comorbid language learning disorders. The authors found that children with ADHD had significantly lower scores on digit span tasks than children without ADHD and that these deficits were more pronounced in children with comorbid language learning disorders.

1.8.3 Digit Span Memory Tests and Cognitive Load in Older Adults:

- Titz, C., Karbach, J. (2014). Working memory and executive functions: Effects of training on academic achievement. Psychological Research, 78(6), 852-868.
- This study examines the cognitive load associated with digit span memory tests in older adults and the effects of training on working memory and executive functions. The authors found that older adults had more difficulty with digit span tasks that required them to hold multiple items in memory simultaneously, and that training on working memory tasks improved their performance on digit span tasks.

1.9 Research Gaps

Here are some potential research gaps in the above articles on digit span memory tests:

1.9.1 Development and Validation of digit span memory tests:

While the WAIS-III is a widely used intelligence test, it has been criticized for its reliance on verbal measures of intelligence and its potential cultural biases. Thus, there may be a need for the development and validation of digit-span memory tests that are more culturally sensitive and that assess other aspects of cognitive ability beyond verbal intelligence.

1.9.2 Digit Span Memory Tests and Attention Deficit Hyperactivity Disorder(ADHD):

While this study found that children with ADHD had lower scores on digit span tasks than children without ADHD, it did not investigate the underlying mechanisms of these deficits. Further research could explore whether deficits in working memory capacity, attentional control, or other cognitive processes contribute to the difficulties that children with ADHD have with digit span tasks.

1.9.3 Digit Span Memory tests and Cognitive Load in older adults:

This study focused on the cognitive load associated with digit span tasks in older adults but did not investigate the potential benefits of cognitive training on other aspects of cognitive function such as processing speed or attentional control. Future research could explore whether cognitive training on working memory tasks improves other cognitive functions in older adults.

1.9.4 Digit Span Memory Tests and individual differences in working memory:

While this study found that performance on digit span tasks was strongly correlated with other measures of working memory capacity, it did not investigate whether there were individual differences in the 7 types of information that people could hold in working memory. For example, some individuals may have greater difficulty holding visual information in memory, while others may struggle with verbal information. Future research could explore individual differences in working memory capacity across different types of stimuli.

1.10 Relating to Research Gaps:

1. Titz and Karbach (2014) investigated the effects of working memory training on academic achievement. One of the cognitive measures they used was the digit span task, which assesses working memory capacity. The objective of their study was to examine the relationship between working memory and academic achievement and to determine whether working memory training improves academic performance.

2. Martinussen and Tannock (2006) examined working memory impairments in children with attention-deficit hyperactivity disorder (ADHD) with and without comorbid language learning disorders. One of the working memory tasks they used was the digit span task. Their objective was to investigate the nature and extent of working memory impairments in children with ADHD and to determine whether working memory deficits are associated with language learning disorders.

3. Wechsler (1997) developed the Wechsler Adult Intelligence Scale (WAIS-III), which includes a digit span subtest to measure working memory capacity. The objective of the WAIS-III is to assess overall intellectual functioning, including working memory.

4. Cowan et al. (2005) conducted a study on the capacity of attention and its role in working memory and cognitive aptitudes. One of the working memory tasks they used was the digit span task. Their objective was to investigate the relationship between attention and working memory capacity and to develop a model of working memory capacity that includes attentional control.

2 Digit Span Test

2.1 Definition

The **Digit Span Test** is used to measure working memory's number storage capacity. Subjects hear a sequence of numerical digits and are tasked to recall the sequence correctly, with increasingly longer sequences being tested in each trial. The participant's span is the longest number of sequential digits that can accurately be remembered.
The **usual procedure for the assessment of digit span is to present the stimulus to the subject for a certain time and simultaneously record the response after a single presentation**. In the case of backward digit span, the subject is presented with the stimulus and asked to respond to it in reverse order.
In fact, digit span has been projected as a screening device that may suggest a hypothesis and that its success or failure as a diagnostic tool lay in the hands of the administrator. The performance on the digit span provides a glimpse into the cognitive makeup of an individual.

2.2 Classification of Digit Span Test

Digit Span Tests can be classified into two types:

2.2.1 Forward Digit Span:

Once the sequence is presented, the subject is asked to recall the sequence in the given order.

2.2.2 Backward Digit Span:

Once the sequence is presented, the subject is asked to recall the sequence in reverse order.

In this project, we have worked on both Forward Digit Span and Backward Digit Span, which helps us in assessing a person's short-term memory and Working memory capacity.

2.3 Advantages of This Method:

- The method is carried out in a very controlled way. The experimenter has a high-level control over all variables.
- Forward Digit Span indicates Short term Memory and Backward Digit Span indicates Working Memory. The findings are reliable.

2.4 Disadvantages of This Method:

- The method is low in ecological validity, i.e. the experimenter is given a high degree of control but it can be criticized due to its artificial nature. This experiment is not representative of the kinds of STM tasks we do in day-to-day life and so are of limited value in extending our knowledge of the capacity of STM.
- It lacks temporal validity, i.e., the findings may not generalize to modern times as it was carried out over 100 years ago.

2.5 Classification of Memorizing Response Errors

Here are the error types with descriptions and examples:

2.5.1 Interchange of Digits(I):

It is the type of error that is observed if two adjacent digits in a particular stimulus interchange their position in the response.
Eg. 185936 and 189536

2.5.2 Repetition of Digit(R):

This error occurs if one digit of a particular stimulus is repeated in the response
Eg. 185936 and 185536

2.5.3 Replacing one Digit by Another(REP):

The type of error that is observed if one digit in the stimulus replaces another to take its place.
Eg. 185936 and 135986

2.5.4 Inclusion of New Digits(ND):

In this case, a completely new digit takes the place of an original digit of the stimulus.
Eg. 185936 and 145936

2.5.5 Leaving out of Digits(LO):

This type of error is said to have occurred if the subject completely leaves out one(or more) digit(s) while responding to a particular stimulus.
Eg. 185936 and 18593

2.5.6 No Response(NR):

This error occurs when the subject gives no response at all.
Eg. Null Response

3 Method

3.1 Participants(Sampling, inclusion, and exclusion criteria)

We have used **snowball sampling** to collect data from participants. Snowball sampling is a non-probability sampling procedure in which the samples have traits or characteristics that are necessary for research purposes. Here is a summary of the information which was collected from the subjects.

1. **Age:** Age of 9 people were less than 20, age of 16 people were 20-50, and the rest 3 were above 50.

2. **Sex:** 10 female and 18 male responses were taken.

3. **Educational Level:** 4 people were of level 1, 14 were of level 2 and 10 were of level 3.

However, as we have collected the data from only our personal networks, there is definitely some bias in the sample that the sample doesn't really represent the whole population and hence the results won't be true in general but will be true for a particular class of people connected through the network.

3.2 Instruments/Tools

We used a computer-assisted tool to determine the digit span of all the subjects. This tool was prepared following the R Script in the IDE called RStudio. The tool, which is basically an R Code written in R Script, included 2 sets of numbers for testing purposes. The subjects were interested beforehand to recall the given set of digits immediately after the presentation of each number on the screen. Finally, we took the average of the 2 outcomes to determine the digit span of that subject.

3.3 Procedure of data collection

3.3.1 Rapport Establishment:

Before the test starts, the researcher must make sure that the subject is in such a mental state that he/she is comfortable with the environment, and is ready to take the test. It is mandatory to let the subject know the reason behind the test. In case of any anxiety or discomfort of the subject, the researcher may try to reduce the subject's tension or anxiety through proper verbal communication.

3.3.2 Rules of Construction of the random numbers:

1. There is no order in the same or between lines.

2. First number will not be the last number of the next line and vice versa.

3. No repetition.

4. 0 after 9 digits once.

5. After 10, you can use one number twice but no order.

3.3.3 Instructions:

The subject should be informed about all the necessary instructions for the experiment in detail. It is better to utter the instructions verbally, as well as through writing. In order to make sure that the subject understands everything completely, we have decided to show the needful instructions before the test begins.

1. Once the test is started, the numbers will begin appearing on the screen. Each number shown on the screen is wiped out after exactly 2 seconds of displaying. The first number can be considered a trial.

2. If the subject guesses the correct number, then he/she is shown the next number with a digit more than the previous one.

3. If the subject makes a wrong guess, the test is still continued. However, as soon as the second mistake is made, the test is stopped there. The number of digits of the last correctly guessed number is noted automatically by the R program.

4. Each subject is tested twice with the help of the R program, The Digit Span of the subject, i.e. the average of the outputs of the 2 tests, is returned as the output of the program, along with the subject's age and gender.

3.3.4 Control:

1. The test was conducted in a noise-free environment.

2. In case of any anxiety or discomfort of the subject, I tried to reduce the subject's tension or anxiety by proper verbal communication, else didn't continue the test and continued it later.

3. Students were used as subjects, as they are expected to have a greater short-term memory capacity.

4. People with psychological disorders (e.g. ADHD) and mentally challenged people were not used as subjects.

3.4 Statistical analysis

After getting the whole data, it is interesting to see the summary statistics category-wise and variation of the digit span through age, whether there exists any good fit of the data, etc. I used Pearson product-moment correlation, Partial Correlation, Histogram, Summary Statistics(Minimum, Maximum, Mean, Median, and quartiles), scatter plot, linear regression, hypothesis testing (one sample and two sample t-test assuming normality), and confidence interval estimation.

4 Results (Interpretation of findings with Tables and figures)

4.1 Descriptive statistics

4.1.1 Summary of Forward Digit-Span

Here is the total summary of the forward digit-span:

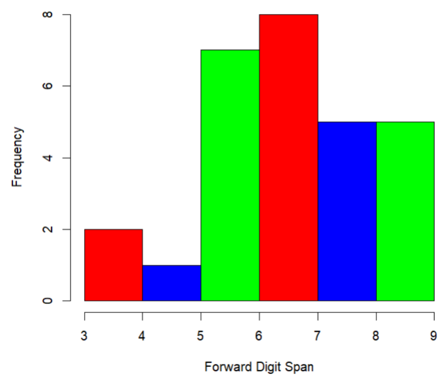

Figure 2: Histogram Plot for Forward Digit Span

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
3.500	6.000	6.750	6.821	8.000	9.000

Figure 3: Total Summary of Forward Digit-Span

- The mean for the age group under 20 is 7.55, that of above 50 is 4.83 and for 20-50, it is 6.32.
- The total s.d. for the forward digit span is 1.510545. So we can clearly see that the total deviation itself is very small and it is expected it will be also less if we do it agewise.
- SD for the under-20 category is found to be 0.6972167, and that of 20-50 is 0.9979145 and for the above-50 category is 1.527525.
- SD for the female category is 1.523884. Here is the summary for the female category:
- SD of the male category is 1.522436. Here is that of the male category:

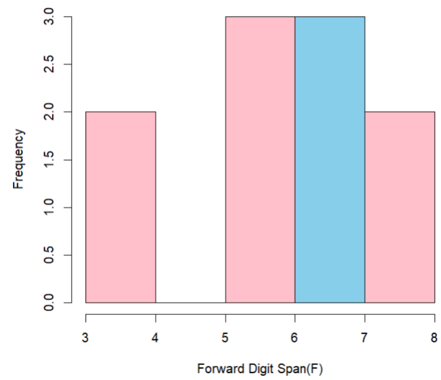

Figure 4: Histogram for Female Category

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
3.50	6.00	6.25	6.10	7.00	8.00

Figure 5: Summary for forward digit-span for FEMALE

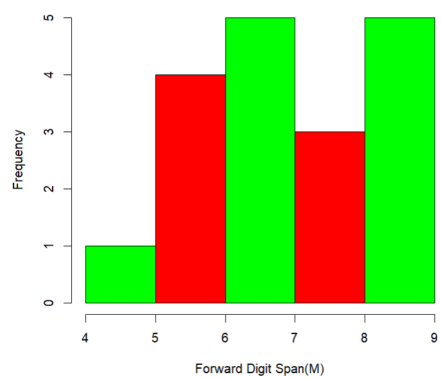

Figure 6: Histogram for Male Category

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
4.500	6.125	7.000	7.222	8.375	9.000

Figure 7: Summary for forward digit-span for MALE

4.1.2 Summary of Backward Digit-span

Here is the total summary of the backward digit span:

- The mean for the age group under 20 is 7.5, and that above 50 is 3.333333 and for 20-50, it is 5.34375.

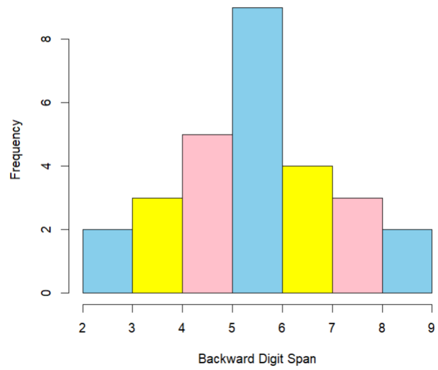

Figure 8: Histogram Plot for Backward Digit Span

```
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
  2.000   5.000   6.000   5.821   7.000   9.000
```

Figure 9: Total Summary of Backward Digit-Span

- The total s.d. for the backward digit span is 1.722478, which is also less. SD for the under-20 category is 1.06066, that of 20-50 is 1.179248, and for the above-50 category is 1.154701.
- So we can see for each case, the s.d. is higher than that of the forward digit span. We discuss the reason in the later section.
- SD for the female category is 1.70049. Here is the summary for the Female category:

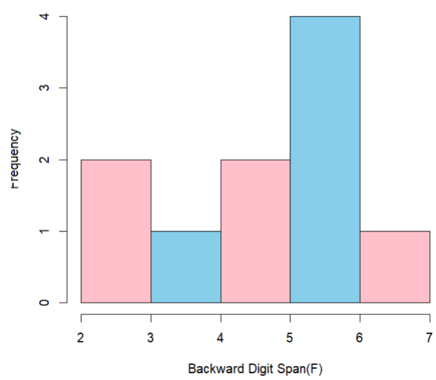

Figure 10: Histogram for Female Category

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
2.00	4.25	5.25	4.85	6.00	7.00

Figure 11: Summary for backward digit-span for FEMALE

- SD of the male category is 1.522436. Here is that for the male category:

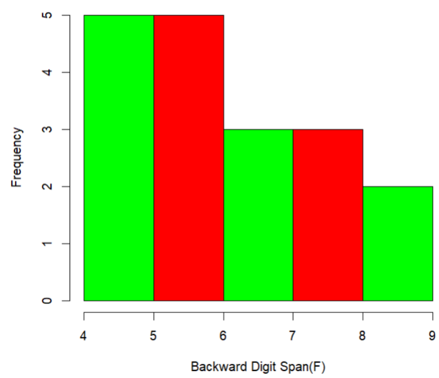

Figure 12: Histogram For Male Category

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
4.000	5.125	6.000	6.361	7.750	9.000

Figure 13: Summary for backward digit-span for MALE

4.2 Inferential statistics

- The pair plot of the whole data is attached in Fig.14.
- Clearly, we can see there is a positive trend in the relation between forward and backward digit-span. And that is quite obvious, because, if one has less forward digit span, he has low short-term memory, then he/she can't work with that, i.e. he/she will have a low working memory, i.e. low backward digit span. Also, the relation between the forward digit span is negative. That is justified by the fact that memory capacity decreases with age. The same goes for backward. But surprisingly we can't see that many relations between educational level and digit span.
- Surprisingly, we notice that there is as such no correlation between education level and digit span, which is very surprising, as generally educated people should have more digit span, but here we show the reverse thing. Why?? We can explain the situation like this: More education implies the person is becoming more aged also. So, his/her educational level

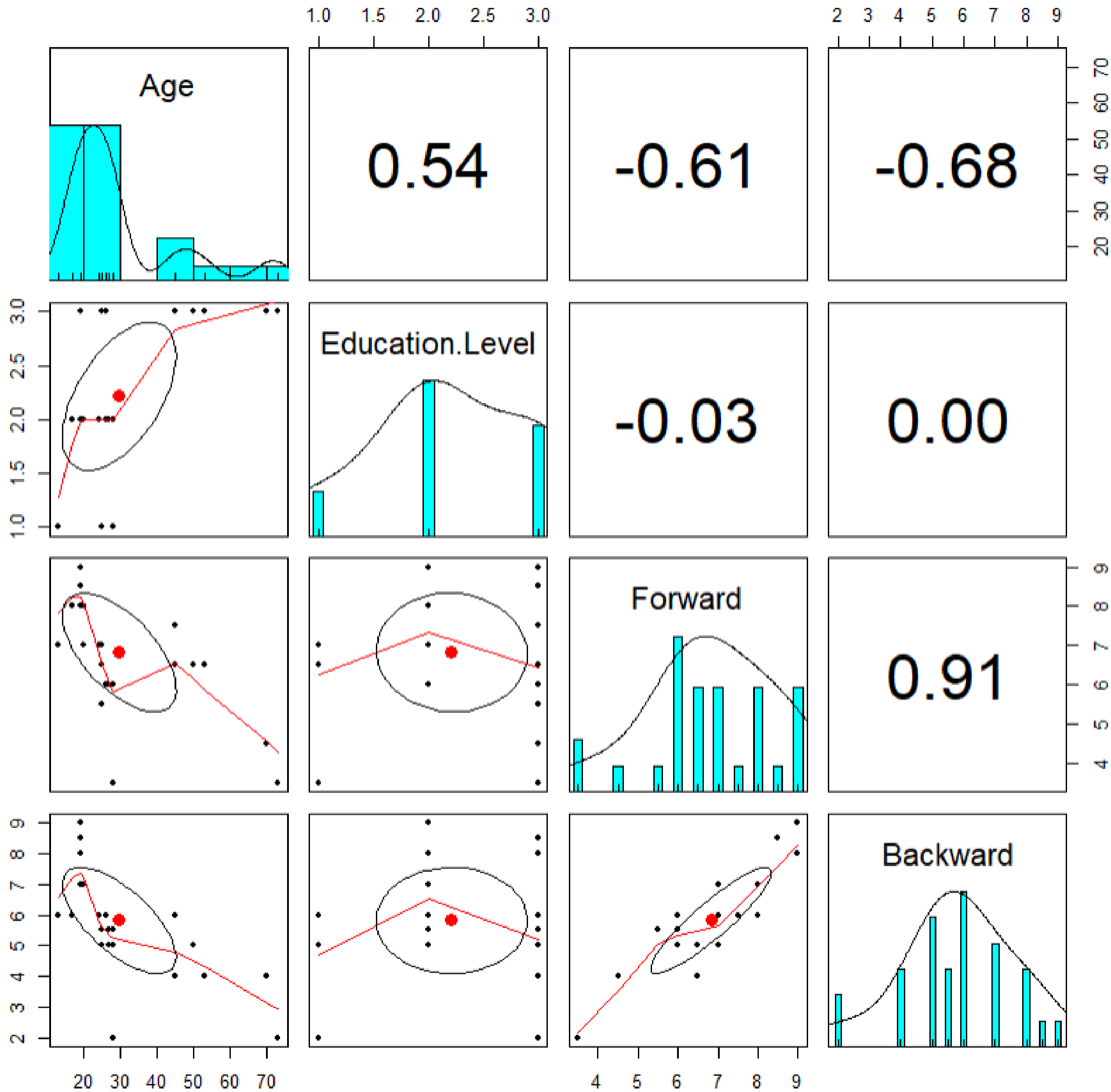

Figure 14: Pair-plot of the data

increasing implies his/her age is also increasing. And, we know that there is a strong negative correlation between age and digit span. So, in the relation of educational level and digit span, there is a strong partial effect of age. So, we may be interested in seeing the partial correlation between educational level and digit span. The partial correlation between X and Y conditioning over Z is defined as follows: $\rho_{XY \cdot Z} = \dfrac{\rho_{XY} - \rho_{XZ}\rho_{ZY}}{\sqrt{1-\rho_{XZ}^2}\sqrt{1-\rho_{ZY}^2}}$. We basically remove the linear effect of Z from both X and Y and then measure the Pearson correlation between them. Here Z is age, X is educational level and Y is digit span. And, the result we got is for forward, it is 0.13, and for backward, it is 0.46 with P values $5.280350 * 10^{-01}$ and $1.708357 * 10^{-02}$. So correlation changed a significant amount as we can see, but due to lack of data, the correlation is not that much positive. Also, in figure 14, we can see that during the change of educational level from 1 to 2, the digit span increases, whereas from 2 to 3, it eventually decreases. This is a strong indication towards the effect of age.

- Also, between age and forward, there is a correlation of -0.61, which is not bad. So, we may be interested in fitting a linear model(for that we have to assume that the digit span is continuous, else we will take the closest one, for example, if the model gives 6.999, we will predict 7 and if gives 7.49, we will predict 7.5). The corresponding graph is in fig.15.

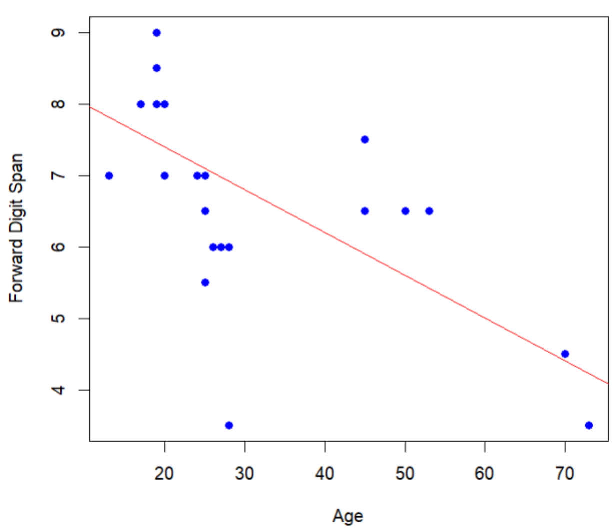

Figure 15: Linear Model between Age and Forward Digit Span

- Now from the graph, we can see that the relationship will be perfect if we make two partitions in the age. We see some randomness started happening after age 40-50. So, it is a better idea to partition the age and we did that. The same for ages below 40 and forward is attached in fig.16.

- In the model in fig.17, the estimate of the slope is -0.05978, that is it is not that good and that picture is reflected in fig.8 also. But when did the same thing for ages below 40, we got a slope of -0.25115 with a p-value of $3.5 * 10^-5$, which is quite significant. Hence the model is good.

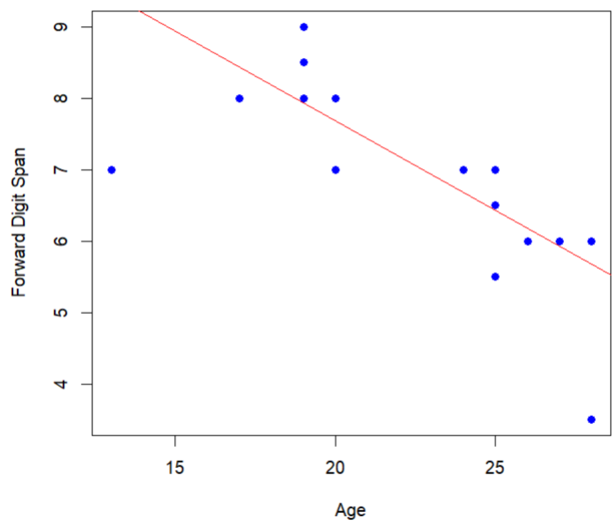

Figure 16: Linear Model Restricted Age and Forward

```
Residuals:
    Min      1Q  Median      3Q     Max 
-3.4154 -0.9154  0.0004  0.9365  1.6009 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  8.58931    0.50124  17.136  1.1e-15 ***
data$Age    -0.05978    0.01507  -3.968 0.000509 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 17: Model between Age and Forward

```
Residuals:
     Min       1Q   Median       3Q      Max 
-2.44259 -0.17763  0.07352  0.50440  1.06431 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 12.70755    1.08326  11.731 2.03e-10 ***
hypo$Age    -0.25115    0.04759  -5.277 3.65e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 18: Model between Restricted Age and Forward

- Same thing we did for backward and got the results attached below. Here we also got better when we removed the age above 40. This may be due to a lack of data above 40, that there might be some other type of relationship with some different linear equation, but as we don't have much data above 40, we aren't able to capture that relationship, if any.
- The restricted age model with backward has a slope p-value of 0.000627, which is quite

significant and a slope value is -0.23965. The third and fourth rows of the first column in the pair plot also indicate the linear model to be split between ages. The age is skewed in its first half, as discussed before. The education level doesn't affect the digit span that much.

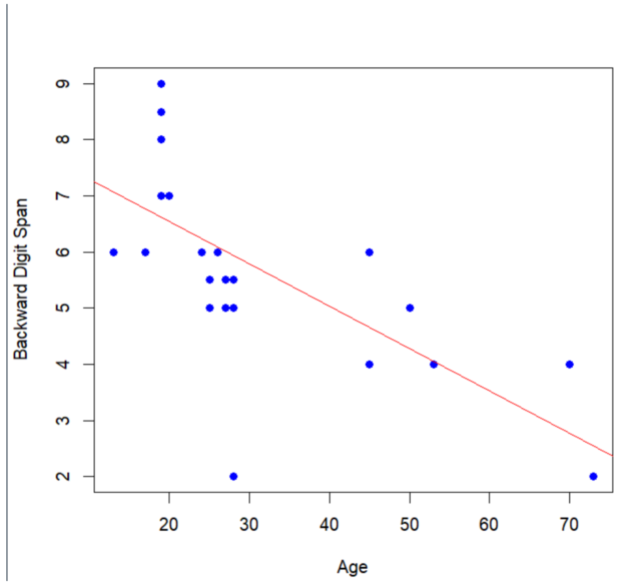

Figure 19: Linear Model between Age and Backward Digit Span

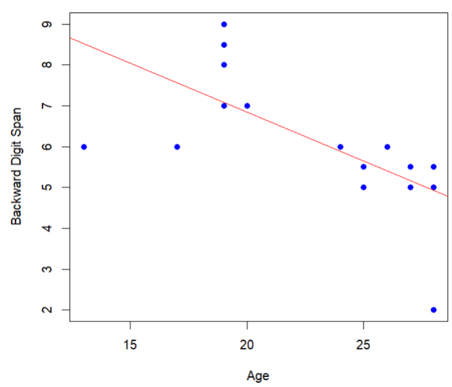

Figure 20: Linear Model Restricted Age and Backward

4.3 Interval Estimation and Hypothesis Testing

- We assume the normality of the Forward digit span data.
- Then we apply a one-sample t-test to test whether the data is coming from a normal

```
Residuals:
    Min      1Q  Median      3Q     Max
-3.9400 -0.6924 -0.0910  0.8478  2.3807

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  8.05329    0.53107  15.164  2.0e-14 ***
data$Age    -0.07547    0.01596  -4.728  6.9e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 21: Model between Age and Backward

```
Call:
lm(formula = hypo$Backward ~ hypo$Age)

Residuals:
    Min      1Q  Median      3Q     Max
-2.9220 -0.1565  0.1401  0.5987  1.9212

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 11.63208    1.34701   8.635 3.51e-08 ***
hypo$Age    -0.23965    0.05918  -4.049 0.000627 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 22: Model between Restricted Age and Backward

distribution with a mean of 6.821. $X_1, .., X_{20} \sim^{iid} N(\mu, \sigma^2)$, σ is unknown.

- $H_0 : \mu = 6.821$, $H_1 : \mu \neq 6.821$.
- Here, σ is unknown, so clearly we will get a one-sample two-sided t-test.
- We perform the test and the null hypothesis is accepted with a p-value of 0.6.
- We get a 95% C.I. [6.01,7.3]
- Similarly, we got very close results for backward digit span, the null hypothesis was accepted with p-value > 0.5 and 95% C.I. [5.089, 6.32]
- And, lastly, we want to see whether the mean for Forward Span for the Female category and Male category on an average matches or not. There are 10 females and 18 males. So, $F_1, ..., F_{10} \sim^{iid} N(\mu_1, \sigma^2)$ and $M_1, .., M_{18} \sim^{iid} N(\mu_2, \sigma^2)$. We assume the variance to be the same and unknown.
- So, $H_0 : \mu_1 = \mu_2$ and $H_1 : \mu_1 \neq \mu_2$. So, here we will get the t statistic from t_{26}, and based on that we will do the two-sided two-sample hypothesis testing.
- After performing the testing, we accept the null hypothesis with a p-value of 0.5.
- Similarly, we do this backward and got similar results.

5 Discussion

5.1 Explaining findings

Here is the summary of the results:

- Education level is not much significant in determining forward digit span. On the other hand, we have seen a nice relationship between age and digit span. Also, we haven't found that much difference for different genders also.
- Mean of forward digit span is 6.821, for age <20 it is 7.55, for 20-50, it is 6.32 and for >50, it is 4.83. The standard deviation in all is less than 1.6.
- Mean of backward digit span is 5.821, and for age <20 it is 7.5, for 20-20, it is 4.85, for >50, it is 3.33.
- We have tried to fit the linear regression model. We have discussed its findings in the corresponding section.
- Statistically we can infer that the digit span decreases as age increases. Working memory or backward digit span is in a good relation with forward based on our data. Also, it depends upon concentration level. But it couldn't be taken into account because there is not any direct way to measure concentration.
- People with more years of education may have better short-term memory and working memory capacity. But, due to a lack of data, it is ambiguous to justify this statement.

5.2 Error Analysis

Now let us discuss what errors we have got while collecting data. The exhaustive general set of errors is discussed before(Sec 2.5). We now discuss those for our case:

- In figure 23,24 there are examples of **LO response error** where the actual was 742613859 and the response was 7426159. the actual was 247913685 and the response was 586942(Backward).
- In figure 26, there is an example of **I and LO** together. The actual was 274169385 and the response was 589361(Backward).
- Also, **REP and R** response errors were also noticed frequently while collecting the data.
- Here is the frequency plot(fig. 23) of how many times what response errors we observed in the data. The indexing here: I Response error is 1, R is 2, REP is 3, ND is 4, LO is 5, NR is 6.

5.3 Relationship with earlier research

This is compatible with earlier research. Here, I have tried to see the relationship between forward and backward digit spans. And we have discussed the findings in the previous subsection.

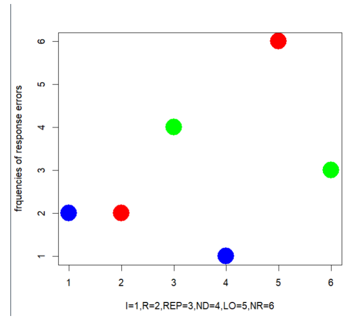

Figure 23: Frequency plot of Response Errors

5.4 Suggestions

No helpful suggestion for improvement was received from the subjects. However, it is probably better to use the verbal or voice method instead of using a digital device like a laptop, because many people are not much comfortable with these electronic devices, which may in turn adversely affect the subject's performance. Also, the results will be more unbiased if we can collect samples from more subjects unbiasedly.

5.5 Future research

- Future research can be done taking some implicit concentration measures into account.
- Also, these digit spans are changed with age. So, a time series analysis on the set of subjects may be helpful to find the distributions and hence finer analysis can be done.
- Also, we can assume some state equations of memory span and apply Kalman Filter to predict future digit span using (possibly 1 step) Markov Model and try to see the pattern.

6 References (APA format)

- A Study on Forward Digit Span Test, Jyotishka Ray Choudhury
- Gregoire, J. Van der Linden, M.(1997). Effect of age on forward and backward digit spans. Aging Neuropsychology and Cognition, 4(2): 140-149.

7 Appendix

7.1 Data

The data is attached in fig.28. Also output and responses of some of the rows are also written in fig 24,25,26,27.

[1] 753	[1] 753	[1] 682	[1] 682
[1] 6479	[1] 6479	[1] 7581	[1] 7581
[1] 41753	[1] 41753	[1] 31685	[1] 31685
[1] 513942	[1] 513942	[1] 931486	[1] 931486
[1] 9258137	[1] 9258137	[1] 3859427	[1] 3859427
[1] 36914752	[1] 36914752	[1] 26914738	[1] 26914738
[1] 624753819	[1] 624753819	[1] 742613859	[1] 7426159

Figure 24: Fwd 1st person, 1st numbers and responses,2nd numbers and responses

[1] 249	[1] 942	[1] 971	[1] 179
[1] 4137	[1] 7314	[1] 3624	[1] 2463
[1] 14293	[1] 39241	[1] 51497	[1] 79415
[1] 583614	[1] 416385	[1] 493518	[1] 815394
[1] 6841752	[1] 2571486	[1] 2413597	[1] 7953142
[1] 52693718	[1] 81739625	[1] 62417958	[1] 85971426
[1] 164283579	[1] 975382461	[1] 247913685	[1] 586942

Figure 25: Bckwd 1st person, 1st numbers and responses and 2nd and responses

[1] 726	[1] 726	[1] 539	[1] 539
[1] 3691	[1] 3691	[1] 6482	[1] 6482
[1] 48319	[1] 48319	[1] 81479	[1] 81479
[1] 728193	[1] 728193	[1] 738294	[1] 738294
[1] 1379584	[1] 1379584	[1] 1357269	[1] 1357269
[1] 25869147	[1] 25869147	[1] 26495813	[1] 26495813
[1] 173846295	[1] 173846295	[1] 427915386	[1] 427915386

Figure 26: Fwd 2nd person, 1st numbers and responses, 2nd numbers and responses

[1] 973	[1] 379	[1] 296	[1] 962
[1] 7916	[1] 6197	[1] 9531	[1] 1359
[1] 53741	[1] 14735	[1] 64172	[1] 27146
[1] 275936	[1] 639572	[1] 746318	[1] 813647
[1] 4725938	[1] 8395274	[1] 9183572	[1] 2753819
[1] 75249136	[1] 63194257	[1] 15397286	[1] 68279351
[1] 274169385	[1] 589361	[1] 573826914	[1] 419628

Figure 27: Bckwd 2nd person, 1st numbers and responses, 2nd numbers and responses

	Age	Gender	Education.Level	Forward	Backward
1	19	M	3	8.5	8.5
2	19	M	3	9.0	8.0
3	45	F	3	6.5	4.0
4	53	M	3	6.5	4.0
5	45	F	3	7.5	6.0
6	19	M	2	9.0	8.0
7	50	M	3	6.5	5.0
8	73	F	3	3.5	2.0
9	17	M	2	8.0	6.0
10	19	M	2	8.0	7.0
11	19	M	2	8.0	7.0
12	19	M	2	9.0	9.0
13	20	F	2	8.0	7.0
14	20	M	2	7.0	7.0
15	19	M	2	9.0	8.0
16	28	F	1	3.5	2.0
17	13	F	1	7.0	6.0
18	70	M	3	4.5	4.0
19	28	M	2	6.0	5.5
20	28	M	2	6.0	5.0
21	27	F	2	6.0	5.0
22	27	F	2	6.0	5.5
23	26	M	2	6.0	6.0
24	26	F	3	6.0	6.0
25	25	M	3	5.5	5.5
26	25	M	1	6.5	5.0
27	25	F	1	7.0	5.0
28	24	M	2	7.0	6.0

Figure 28: Data

7.2 Stem leaf plot of original data

From figure 29, there are two 3.5, three 6.0, one 6.5, two 7.0, one 7.5, and one 8.0 in females. And, in males, there are one 4.5, 5.5,8.5, three 6.0, 6.5, 8.0, two 7.0, and four 9.0. From figure 30, there are two 2.0, three 4.0, one 4.5, and four 6.0 in females. And, in males, there are five 4.0, two 4.5, six 6.0, four 8.0, and one 8.5.

7.3 The tools with instructions

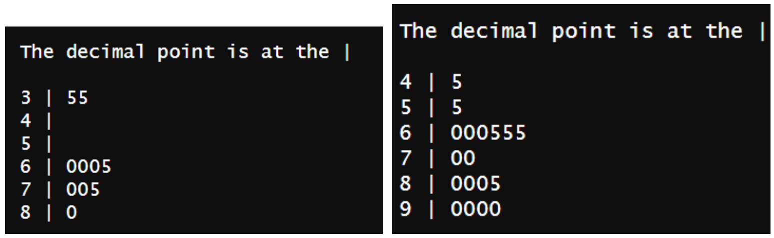

Figure 29: Stem leaf plot of Forward digit span Female and Male side by side

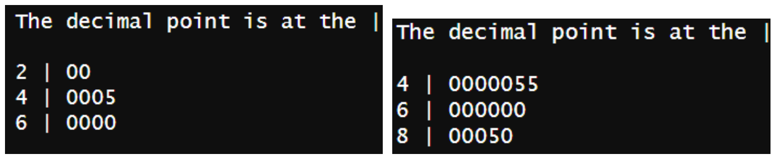

Figure 30: Stem leaf plot of Backward digit span Female and Male side by side

```
Forward Digit Span:
#### Author : SRIJAN CHATTOPADHYAY
#### Affiliation : INDIAN STATISTICAL INSTITUTE, KOLKATA
#### Designation : STUDENT, B.STAT 2ND YEAR
#FORWARD DIGIT SPAN TEST

random.numbers <- function(){

  random.digits <- function(n){

    # Randomly generating distinct digits of the numbers

    k=0
    l=0
    while (k==0)
    {
      number <- sample(1:9 , size = n , replace = FALSE)
      for(i in 2:length(number))
      {
        if(number[i]==number[i-1]+1 ||
        number[i]==number[i-1]-1) #checking the intra-line conditions
          l=l+1
      }
      if(l == 0) k=1
      else
      {k=0
      l=0}}

    return(number)
```

```
  }

  test.data <- c()
  data <- c()
  a=random.digits(3)
  test.data = c(test.data, a)
  data = c(data, as.numeric(paste(a, collapse = "")))
  for (i in 4:9) {
    h=0
    while(h==0)
    {
      a=c(test.data[(i-3)*(i+2)/2-(i-1)+1] : test.data[(i-3)*(i+2)/2])
      g=0
      h=0
      b=random.digits(i)
      if(b[1]==a[1] || b[1]==a[length(a)] ||
      b[length(b)]==a[length(a)] || b[length(b)]==a[1])
      #checking the inter line conditions
      {
        g=g+1
      }
      if(g==0) h=1
      else h=0}
    test.data = c(test.data, b)
    data = c(data, as.numeric(paste(b, collapse = "")))
  }

  return(data) # Vector containing all the numbers
}



cat("\f")
cat("\nStarting the digit span test...\n\n")  # Instructions
Sys.sleep(2)

cat("The purpose of this experiment is to find out your digit span /
memory span. \n\n")
cat("=====================================================================\n\n")
Sys.sleep(3)

cat("INSTRUCTIONS :\n\n")
cat("(1) Starting from a 3-digit number, each number will
appear one by one after an interval of 2 seconds. In order to proceed,
you'll have to make the correct guess.\n\n")
cat("(2) At each step, the number of digits will increase by 1. If you
make one mistake somewhere, you'll be able to proceed. If you make 2
mistakes, the experiment will stop there.\n\n")
```

```r
cat("(3) The test will be conducted 2 times.\n\n")
Sys.sleep(2)

cat("All the best !\n\n")

## Details about the participant ##

name <- readline(prompt = "Enter your name : ")
age <- readline(prompt = "Enter your age : ")
gender <- readline(prompt = "Enter your gender [M / F] : ")
education <- readline(prompt = "Enter your years of education : ")

if (gender != "M" && gender !="m" && gender != "F" && gender != "f"){
    print("Invalid gender input !") # Checkpoint for invalid gender input
    stop("\n\nPlease try again.\n\n")
}
if (gender == "M" || gender == "m"){gender <- "MALE"}
if (gender == "F" || gender == "f"){gender <- "FEMALE"}

cat("\n\n")


## Main function for conducting the experiment ##

final.exp <- function(d){
  begin <- readline(prompt = "Ready to start the test ? [Y / N] : ")
  cat("\f")

  if (begin == "Y" || begin == "y") {

    # Random numbers are generated for a particulat experiment
    exp.data <- random.numbers()

    cat("Experiment number ",d," will start in 4 seconds...\n\n")
    Sys.sleep(4)
    cat("\f")

    # Initial count for number of mistakes
    count <- 0

    for (num in exp.data) {

      # Each number is printed in the R Console
      print(num)

      # Waiting time of 2 seconds
      Sys.sleep(2)
      cat("\f")
```

```
# Subject's response
guess <- readline(prompt = "Guess the number : ")

# Condition for CORRECT guess
if (guess == num){
  if (num != exp.data[length(exp.data)]){
    cat("\f")
    cat("The next number will appear in 3 seconds...\n\n")
    Sys.sleep(3)
  }

  if (num == exp.data[length(exp.data)]) {
    cat("\n Your test #",d,"is over. You guessed ",
        floor(log10(num))-1-count,
        " numbers correctly.\n\n")
    return(floor(log10(num))+1)
  }
}

cat("\f")

# Condition for INCORRECT guess
if (guess != num){
  count <- count + 1

  # 1st mistake
  if (count == 1){
    if (num != exp.data[length(exp.data)]){
      first <- floor(log10(num)) + 1
      cat("The next number will appear in 3 seconds...\n\n")
      Sys.sleep(3)
      cat("\f")
    }

    if (num == exp.data[length(exp.data)]){
      cat("Your test #",d,"is over. You guessed ",
      floor(log10(num)) - 2," numbers correctly.\n\n")
      return(floor(log10(num)))
    }
  }

  # 2nd mistake
  if (count == 2){
    second <- floor(log10(num)) + 1
    if (num == exp.data[2]) {return(0)}

    cat("Your test #",d,"is over. You guessed ",
```

```
                floor(log10(num))-3," numbers correctly.\n\n")

          if (first != second - 1) {return(second - 1)}
          if (first == second - 1) {return(first - 1)}
        }
      }
    }
  }
  else stop("You have chosen not to proceed !\n\n")
}



## 1st test ##

F1 <- final.exp(1)
if (F1 == 0) {
  cat("\n\nYour test could not be completed.\n\n")
  cat("If you want, you may try again. Thank you.\n\n")
  stop("Good luck.\n\n")
}


## 2nd test ##

F2 <- final.exp(2)
if (F2 == 0) {
  cat("\n\nYour test could not be completed.\n\n")
  cat("If you want, you may try again. Thank you.\n\n")
  stop("Good luck.\n\n")
}


# Final calculation of the participant's forward digit span
digit.span <- mean(c(F1,F2)) # Average digit span

# Digits span printed as a sentence
cat("As per the most recent test,
the digit span of",name,"is",digit.span,".\n\n")
Sys.sleep(2)
cat("Thank you for taking the test.\n\n")

# Overall result stored as a data frame variable
result <- data.frame(NAME = name , AGE = age , GENDER = gender ,
                     EDUCATION = education , TEST.1 = F1 , TEST.2 = F2 ,
                     DIGIT.SPAN = digit.span)

print(result)
```

```
cat("\n")
View(result) # Overall result printed in a chart format
Backward Digit Span:
#### Author : SRIJAN CHATTOPADHYAY
#### Affiliation : INDIAN STATISTICAL INSTITUTE, KOLKATA
#### Designation : STUDENT, B.STAT 2ND YEAR
#BACKWARD DIGIT SPAN TEST


#install.packages("stringi")
library(stringi)
random.numbers <- function(){

  random.digits <- function(n){

    # Randomly generating distinct digits of the numbers

    k=0
    l=0
    while (k==0)
    {
      number <- sample(1:9 , size = n , replace = FALSE)
      for(i in 2:length(number))
      {
        if(number[i]==number[i-1]+1 ||
        number[i]==number[i-1]-1) #checking the intra-line conditions
          l=l+1
      }
      if(l == 0) k=1
      else
      {k=0
      l=0}}

    return(number)
  }

  test.data <- c()
  data <- c()
  a=random.digits(3)
  test.data = c(test.data, a)
  data = c(data, as.numeric(paste(a, collapse = "")))
  for (i in 4:9) {
    h=0
    while(h==0)
    {
      a=c(test.data[(i-3)*(i+2)/2-(i-1)+1] : test.data[(i-3)*(i+2)/2])
      g=0
      h=0
```

```
      b=random.digits(i)
      if(b[1]==a[1] || b[1]==a[length(a)] || b[length(b)]==a[length(a)] || b[length(b)]
      {
        g=g+1
      }
      if(g==0) h=1
      else h=0}
    test.data = c(test.data, b)
    data = c(data, as.numeric(paste(b, collapse = "")))
  }

  return(data) # Vector containing all the numbers
}



cat("\f")
cat("\nStarting the digit span test...\n\n")  # Instructions
Sys.sleep(2)

cat("The purpose of this experiment is to find out your digit span /
memory span. \n\n")
cat("======================================================================\n\n")
Sys.sleep(3)

cat("INSTRUCTIONS :\n\n")
cat("(1) Starting from a 3-digit number, each number will
appear one by one after an interval of 2 seconds. In order to proceed,
you'll have to make the correct guess.\n\n")
cat("(2) At each step, the number of digits will increase by 1. If you
make one mistake somewhere, you'll be able to proceed. If you make 2
mistakes, the experiment will stop there.\n\n")
cat("(3) The test will be conducted 2 times.\n\n")
Sys.sleep(2)

cat("All the best !\n\n")

## Details about the participant ##

name <- readline(prompt = "Enter your name : ")
age <- readline(prompt = "Enter your age : ")
gender <- readline(prompt = "Enter your gender [M / F] : ")
education <- readline(prompt = "Enter your years of education : ")

if (gender != "M" && gender !="m" && gender != "F" && gender != "f"){
  print("Invalid gender input !") # Checkpoint for invalid gender input
  stop("\n\nPlease try again.\n\n")
}
```

```
if (gender == "M" || gender == "m"){gender <- "MALE"}
if (gender == "F" || gender == "f"){gender <- "FEMALE"}

cat("\n\n")


## Main function for conducting the experiment ##

final.exp <- function(d){
  begin <- readline(prompt = "Ready to start the test ? [Y / N] : ")
  cat("\f")

  if (begin == "Y" || begin == "y") {

    # Random numbers are generated for a particulat experiment
    exp.data <- random.numbers()

    cat("Experiment number ",d," will start in 4 seconds...\n\n")
    Sys.sleep(4)
    cat("\f")

    # Initial count for number of mistakes
    count <- 0

    for (num in exp.data) {

      # Each number is printed in the R Console
      print(num)

      # Waiting time of 2 seconds
      Sys.sleep(2)
      cat("\f")

      # Subject's response
      guess <- readline(prompt = "Guess the number : ")

      library(stringi)

      # Condition for CORRECT guess
      if (guess == stri_reverse(num)){
        if (num != exp.data[length(exp.data)]){
          cat("\f")
          cat("The next number will appear in 3 seconds...\n\n")
          Sys.sleep(3)
        }

        if (num == exp.data[length(exp.data)]) {
          cat("\n Your test #",d,"is over. You guessed ",
```

```
            floor(log10(num))-1-count,
            " numbers correctly.\n\n")
          return(floor(log10(num))+1)
        }
      }

      cat("\f")

      # Condition for INCORRECT guess
      if (guess != stri_reverse(num)){
        count <- count + 1

        # 1st mistake
        if (count == 1){
          if (num != exp.data[length(exp.data)]){
            first <- floor(log10(num)) + 1
            cat("The next number will appear in 3 seconds...\n\n")
            Sys.sleep(3)
            cat("\f")
          }

          if (num == exp.data[length(exp.data)]){
            cat("Your test #",d,"is over. You guessed ",
                floor(log10(num)) - 2," numbers correctly.\n\n")
            return(floor(log10(num)))
          }
        }

        # 2nd mistake
        if (count == 2){
          second <- floor(log10(num)) + 1
          if (num == exp.data[2]) {return(0)}

          cat("Your test #",d,"is over. You guessed ",
              floor(log10(num))-3," numbers correctly.\n\n")

          if (first != second - 1) {return(second - 1)}
          if (first == second - 1) {return(first - 1)}
        }
      }
    }
  }
  else stop("You have chosen not to proceed !\n\n")
}



## 1st test ##
```

```r
F1 <- final.exp(1)
if (F1 == 0) {
  cat("\n\nYour test could not be completed.\n\n")
  cat("If you want, you may try again. Thank you.\n\n")
  stop("Good luck.\n\n")
}


## 2nd test ##

F2 <- final.exp(2)
if (F2 == 0) {
  cat("\n\nYour test could not be completed.\n\n")
  cat("If you want, you may try again. Thank you.\n\n")
  stop("Good luck.\n\n")
}


# Final calculation of the participant's forward digit span
digit.span <- mean(c(F1,F2)) # Average digit span

# Digits span printed as a sentence
cat("As per the most recent test, the digit span
of",name,"is",digit.span,".\n\n")
Sys.sleep(2)
cat("Thank you for taking the test.\n\n")

# Overall result stored as a data frame variable
result <- data.frame(NAME = name , AGE = age , GENDER = gender ,
                     EDUCATION = education , TEST.1 = F1 , TEST.2 = F2 ,
                     DIGIT.SPAN = digit.span)

print(result)
cat("\n")
View(result) # Overall result printed in a chart format
```