A Study on Forward Digit Span Test

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1 General Problem

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

2 Specific Problem

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

3 Basic Concept

3.1 Multi-Store 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, the 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 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. The 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 the 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.

3.2 Digit Span Test

3.2.1 Definition

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.

3.2.2 Classification

Digit Span Test can be classified into two types :

- **Forward Digit Span:** Once the sequence is presented, the subject is asked to recall the sequence in given order.
- **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 the Forward Digit Span only, which helps us in assessing a person's short-term memory capacity.

3.2.3 Advantages

- The method is carried out in a very controlled way. Experimenter has a high level control over all variables.
- The findings are reliable.

3.2.4 Disadvantages

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

4 Preliminaries

4.1 Subject Characteristics

We have collected information from the subjects regarding Age, Sex, Educational level and Socio-economic Status. These are necessary for further studies on Digit Span. We have used snowball sampling (or, Chain-referral Sampling) to collect data from 20 individuals, which is defined to be a non-probability sampling procedure in which the samples have traits or characteristics that are necessary for research purposes. Here a summary of the information which were collected from the subjects:
(1) Age : The average age of the subjects was found out to be approximately 37.7 years, and the standard deviation of their ages was 21.68999 years. The range of ages was 17 years - 77 years.
(2) Sex : Among the 10 subjects, it was observed that 4 were males, and the rest (6 in number) of the subjects were females.
(3) Educational level : We have categorized the educational qualifications of the subjects in the following manner :
• Level 1 : Had at most 10 years of study, i.e. didn't graduate or just graduated from high school.
• Level 2 : Continued further studies after 10th standard, but did not graduate, or yet to graduate so far.
• Level 3 : Graduated, and has a degree in some discipline of study.
(4) Socio-economic status : All of the subjects belong to middle-class families. There might slight variations, but on a whole, all of them came from families with moderate income.

4.2 Customized Digit Span Test

We have used R code to generate random numbers for the test. We have followed some specific rules for the Digit Span Test, unlike the general Digit Span Test, which are mentioned later.

5 Test

5.1 Description

In the experiment, independent variable is the 2 sets of Digit Span tests, and the dependent variable is memory span. The digits of each number (i.e. the whole number itself) were generated randomly to reduce bias, following all the rules of Customized Digit Span Test. We have used the "sample" function in R for the task of generation of the random numbers of length 3 to 13 in strictly increasing order.

5.2 Rules for Construction

- In a number, consecutive digits should be different.
- In a number, consecutive gaps between two digits must be different.
- First digit of a number will not come at end of the previous number.
- We have to generate random numbers of length 3 to 13 in strictly increasing order.

5.3 Scoring

- Once the test is started, the numbers will begin to appear on the screen. Each number shown on the screen is wiped out aer exactly 2 seconds of displaying. The first number can be considered as a trial.
- If the subject guesses the correct number, then he/she is shown the next number with a digit more than the previous one.
- 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.
- Each subject is tested twice with the help of the R Program. The Digit Span of the subject, i.e. the average the outputs of the 2 tests, is returned as the output of the program.

6 Procedure

6.1 Data Collection

In order to increase variability in the data, we have collected data from various age ranges, socio-economic status, different educational levels and from both males and females.

6.2 Statistical Analysis

We have used descriptive statistics like central tendency, and variability statistics like measures of dispersion (e.g. Standard Deviation, Variance etc.) to study the average digit spans of the subjects and their variations. The average digit spans were determined with differences in age, sex, and educational level.

6.3 Control

- There must not be any noise during the test.
- In case of any anxiety or discomfort of the subject, the researcher may try to reduce the subject's tension or anxiety by proper verbal communication, else should not continue the test.
- Students may be used as subjects, as they are expected to have a greater short-term memory capacity.
- People with psychological disorders (e.g. ADHD) and mentally challenged people should not be used as subjects.

7 Results

7.1 Individual

We have found the following results:

- When all the subjects were included in the study, the average digit span was found out to be 6.8 , and the s.d. was found out to be 2.110819. It ranged from 3.5 to 10.
- There are 6 subjects in age ranges 15-30, with mean 7.166667 and s.d. 2.316607. There are 4 subjects in age ranges 31-above, with mean 6.25 and s.d. 1.936492. So it can be observed that as age increases, there's a tendency of Digit Span to decrease. So, possibly, our short-term memory capacity decrease as our age increase.
- Subjects with level 1 has mean 3.75 and s.d. 0.3535534. Subjects with level 2 has mean 7.583333 and s.d. 1.800463. Subjects with level 3 has mean 7.5 and s.d. 0.7071068. So subjects with level 1 has lesser digit span than other subjects.

- Females have mean 6.5 and s.d. 2. Males have mean 7.25 and s.d. 2.5. So the average digit span of male subjects is greater than the average digit span of the female subjects. However, in the data which we collected, the only person with age greater than 70 is a female, and her digit span is quite small. That's why, it is difficult to make strong comments on the influence of sex / gender on digit span of a person.
- **Table for Digit Span w.r.t. Age and Educational Level:**

Age(In Years)	Educational Level					
	Level 1		Level 2		Level 3	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
15-30	4	0	7.8	1.923538	N/A	N/A
31-above	3.5	0	6.5	0	7.5	0.7071068

So as Education level increases, people have greater Digit Span. Also, as age increases, the table also reflects that the average digit spans of the subjects have diminished.

- **Table for Digit Span w.r.t. distributions of Age and Sex:**

Age(In Years)	Sex/Gender			
	Male		Female	
	Mean	S.D.	Mean	S.D.
15-30	7.333333	3.05505	7	2
31-above	7	0	6	2.291288

So the female subjects have smaller digit spans than the male subjects for all age categories. However, if we consider the fact that the only outlier (The person with age 77) is a female, so it is ambiguous to make a general statement regarding the influence of sex / gender on digit span.

- **Table for Digit Span w.r.t. Sex and Educational Level:**

Sex/Gender	Educational Level					
	Level 1		Level 2		Level 3	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Male	4	0	9	1.414214	7	0
Female	3.5	0	6.875	1.652019	8	0

We can see that males with education level 2 have a very high digit span and females with education level 1 have a very poor digit span.

7.2 Actual Digit

Actual random digits used are mentioned below in order:

- 728
  4791
  79614
  968716
  3247648
  17349153
  618598391
  8174629152
  35248594879

512941869735
7462314359178

In first attempt, the subject guessed upto the number "618598391".

782
4657
17958
931845
9438732
81378638
714387162
1758719653
97863193869
873472318358
9143758247925
In second attempt, the subject guessed upto the number "714387162".

- 871
  7857
  52693
  217643
  4139763
  54984291
  625635914
  6813421875
  15835627364
  138437632796
  3613496194236
  In first attempt, the subject guessed upto the number "4139763".

457
2431
81631
726358
3426742
93528715
386187259
7612671397
67523793176
493853816931
5195281245268
In second attempt, the subject guessed upto the number "3426742".

- 176
  8735
  94193
  743825
  9532637
  95862487

527953819
6958625714
16384274976
781946932641
3726482964813
In first attempt, the subject guessed upto the number "9532637".

731
3589
54196
293425
3613971
75978537
658378698
9524793745
26594536879
238537592618
9578257437152
In second attempt, the subject guessed upto the number "293425".

- 754
  7682
  89621
  395475
  4786259
  59764914
  657462764
  2431742572
  71632685764
  572179247597
  3518391874635
  In first attempt, the subject guessed upto the number "4786259".

  518
  7867
  93673
  936195
  2861461
  76841247
  581793473
  6186756215
  75483542762
  381253256921
  7632593621948
  In second attempt, the subject guessed upto the number "2861461" .

- 769
  3253
  86724
  791241
  6193657
  67594528

791253682
5194263754
32518968597
256379549615
3426536417589
In first attempt, the subject guessed upto the number "3253" .

965
2958
71842
196174
7958278
15813281
795617485
6193629768
36435145264
685927167453
2764873649673
In second attempt, the subject guessed upto the number "2958" .

- 576
2972
54872
354853
6178512
69819658
793273614
7845879532
72983275492
637137697823
9315394317325
In first attempt, the subject guessed upto the number "69819658".

716
5324
32867
365362
5784381
28613861
713742564
5879431756
59743895745
126412561469
7981934934216
In second attempt, the subject guessed upto the number "28613861".

- 716
9167
35149
814297
1682137
63793815
764574624

5169462841
24825129145
138591279368
1924527564576
In first attempt, the subject guessed upto the number "716".

769
8248
21648
497359
6891641
38198537
293296872
5179485386
21784783657
423612835182
3465264537142
In second attempt, the subject guessed upto the number "8248".

- 498
1263
53269
821784
2549734
97289165
185341825
1738249586
17215487139
482493153812
9853915724928
In first attempt, the subject guessed upto the number "1738249586".

967
9178
59764
865934
2165365
37942314
286954926
1632983546
96893568329
273812791762
7953681261981
In second attempt, the subject guessed upto the number "1632983546".

- 125
4862
62352
394152
7526537
24391893
619867962
1875139865

71526826482
634153275649
3674859763486
In first attempt, the subject guessed upto the number "24391893".

354
6483
95726
863172
3928965
67591851
364834698
2184736413
13953473561
427697352865
8962916527189
In second attempt, the subject guessed upto the number "67591851".

- 139
  4298
  47549
  856325
  4829164
  51932572
  896257625
  9358256197
  27586398651
  871942618652
  8912853742967
  In first attempt, the subject guessed upto the number "856325" .

  872
  5412
  17298
  682712
  9164378
  34127461
  549547849
  5286354281
  41763149389
  682475419624
  8431783259349
  In second attempt, the subject guessed upto the number "5412".

7.3 Subject's Response

Responses of the Forward Digit Span Test is given below:

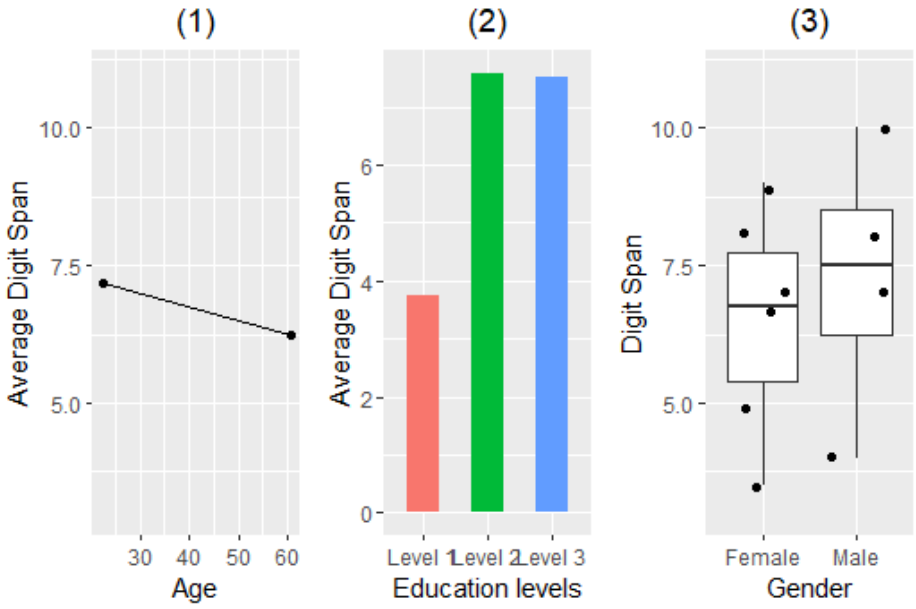
S.NO.	Sex/Gender of the Subject	Age of the Subject	Level of Education	Digit Span of Subject
1	Female	20	Level 2	9
2	Male	65	Level 3	7
3	Female	55	Level 2	6.5
4	Female	19	Level 2	7
5	Male	29	Level 1	4
6	Female	46	Level 3	8
7	Female	77	Level 1	3.5
8	Male	19	Level 2	10
9	Male	17	Level 2	8
10	Female	30	Level 2	5

8 Interpretation

8.1 Inter-individual comparison

Due to the lack of number of subjects, considering current situation, individual to individual comparison does not make much sense. However, on an overall basis, we can observe that younger people (17-20 years) have digit span mostly greater than or equal to 7. The oldest subjects and the subjects with the least amount of education did not perform that much well, probably due to lack of vision and reflexes respectively.

Below, the plots (1), (2) and (3) are line chart, bar chart and boxplot respectively, which are diagrammatic representation of how the independent variables influence the average digit spans:



8.1.1 Observations

- From the regression line, it is clear that as age increases, the digit span of the subjects decrease on an overall basis. So, possibly, short-term memory is adversely affected by the natural ageing process.
- Again, from the regression line, it can be seen the people with more years of education have greater digit span.
- On a whole, it can be observed that males performed beer than the females.

9 Conclusion

Considering the current situation, the provision of collecting data (i.e. implementing the experiment) from different subjects was quite difficult. So the number of subjects who participated in the test is 10, which is a quite small sample to work with. We may summarize our whole experiment by saying that our age, education, gender etc. influence our memory span, and hence they are some controlling factors of our short-term memory capacity. From our analysis, it seems that as age increases, digit span decreases ; as our more formal education implies better short-term memory ; and males have possibly beer short-term memory than females.

10 References

- Encyclopedia of Clinical Neuropsychology: Jeffrey S. Kreutzer, John DeLuca, Bruce Captain.
- Eect of age on forward and backward digit spans. Aging Neuropsychology and Cognition : Babcock, R.L. Salthouse, T.A.

11 R Codes Used

11.1 R Codes for the Experiment

```
Experiment<- function(){
random.numbers <- function(){
  random.digits <- function(n){
    a<-sample(1:9,size=1)
    number<-a
    b<-a
    c<-a
    i<-1
    while(i < 2){
      a<-sample(1:9,size=1)
      if(a!=b)
      {
        number<-10*number+a
        b<-a
        i=i+1
      }
    }
    while(i < n){
      a<-sample(1:9,size=1)
      if(a!=b && abs(a-b)!=abs(b-c))
      {
        number<-10*number+a
        c<-b
        b<-a
        i=i+1
      }
    }
    return(number)
  }
  test.data <- c()
  i=3
  a<-c()
  a[i-2]=random.digits(3)
```

```
  test.data <- c(test.data , a[i-2])
  i=i+1
  while(i < 14) {
    a[i-2]=random.digits(i)
    if((a[i-3]%%10)!=floor(a[i-2]/10^(i-1))){
    test.data <- c(test.data , a[i-2])
    i=i+1
    }
  }
  return(test.data)
}
cat("\f")
cat("\nStarting the digit span test...\n\n")
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")
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 highest educational qualification : ")

cat("\n\n")
final.exp <- function(d){
  begin <- readline(prompt =

                      "Ready to start the test ? [Y / N] : ")
  cat("\f")
  if (begin == "Y" || begin == "y") {
    exp.data <- random.numbers()
    cat("Experiment number ",d," will start in 4 seconds...\n\n")
    Sys.sleep(4)
    cat("\f")
    count <- 0
    for (num in exp.data) {
      print(num)
      Sys.sleep(2) # Waiting time of 2 seconds
      cat("\f")
      guess <- readline(prompt = "Guess the number : ")
      # Subject's response
      if (guess == num){ # Condition for correct guess
        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")
      if (guess != num){ # Condition for wrong guess
        count <- count + 1
        if (count == 1){ # First mistake
          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)))
          }
        }
        if (count == 2){ # Second mistake
          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")
}
F1 <- final.exp(1) # 1st test
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")}
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")}
dspan <- mean(c(F1,F2)) # Average digit span
cat(name,"'s digit span is ",dspan,".\n\n")
# Digits span printed as a sentence
Sys.sleep(2)
cat("Thank you for taking the test.\n\n")
```

```
}
```

11.2 R Codes for the Plots

```
require(ggplot2)
require(patchwork)
library(ggeasy)
age<-c(20,65,55,19,29,46,77,19,17,30)
dsp<-c(9,7,6.5,7,4,8,3.5,10,8,5)
gend<-c("Female","Male",rep("Female",2),"Male",rep("Female",2),rep("Male",2),"Female")
educ<-c(2,3,2,2,1,3,1,2,2,2)
gend2 <- gend
z <- factor(gend2,levels = c("Female","Male"))
gend[gend=="Female"] <- 1
gend[gend=="Male"] <- -1
gend <- as.numeric(gend)
df <- data.frame(GENDER = gend, AGE = age, EDU = educ, DIGIT.SPAN = dsp)
df2 <- data.frame(GENDER = z, AGE = age, EDU = educ, DIGIT.SPAN = dsp)
age.dsp<-c(7.166667,6.25)
age.avg<-c(22.33333,60.75)
finplot1 <- qplot(age.avg , age.dsp ,geom = c("point","line"), main = "(1)") +
  xlab("Age") + ylab("Average Digit Span") +
  ggtitle("(1)") + ylim(c(3,11)) +
  ggeasy::easy_center_title()
edu.dsp <- data.frame(Levels = c("Level 1" , "Level 2" ,
                                 "Level 3") , edu.level.dsp = c(3.75 , 7.583333 , 7.5))
finplot2 <- ggplot(edu.dsp,aes(Levels,
                               edu.level.dsp, fill = Levels)) +
  geom_bar(stat = "identity",width = 0.5) +
  xlab("Education levels") + ylab("Average Digit Span") +
  ggtitle("(2)") + ggeasy::easy_center_title() +
  theme(legend.position = "none" )
finplot3 <- qplot(z, dsp, data = df2,
                  geom=c("boxplot" , "jitter"),
                  xlab="Gender", ylab="Digit Span") +
  ggtitle("(3)") + ylim(c(3,11)) +
  ggeasy::easy_center_title() +
  theme(legend.position = "bottom")
final <- finplot1 + finplot2 + finplot3
print(final)
```