The List Length Effect and Immediate Free Recall of Visually Displayed Information in Various Forms

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Abstract **– This paper investigated four main phenomena connected with the free immediate recall and visual representation of the information: list-length effect, serial position effect, horizontal versus vertical presentation of the information, expression of the information in the form of the symbol, text, and symbol with text. The number of examined respondents was 4140. The experiment revealed a different memory recall of various forms of visually displayed information and studied a dependency of list length effect on primacy and recency effect. The results showed that people recall better the combination of symbols and text than only text or symbols. The other finding indicated a significant difference between the number of recalled items in the tests of 5, 7, and 9 items. The respondents recalled the highest number of items in 5-item tests and the lowest number in 9-item tests. There was investigated that the proportions of the respondents recalling the items from the beginning is higher than those of the respondents recalling the items from the end. The results showed that the primacy effect was higher than the recency effect regardless of the list length (5, 7, or 9 items tests). This article's findings should help design visually optimized websites and applications.**

Keywords **– Serial position effect, user experience, memory, free recall, list length effect.**

DOI: 10.18421/TEM123-34
https://doi.org/10.18421/TEM123-34

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Received: 11 October 2022.
Revised: 20 May 2023.
Accepted: 02 August 2023.
Published: 28 August 2023.

1. Introduction

Memory in the context of visually displayed information plays a significant role in user behavior while a user is on a website. Interfaces of websites, applications, or programs are often flooded with many components, design variables, colors, and shapes. User is usually meant to recall and remember much content or information.

Too much content or information on the website can be acknowledged as a struggle or difficulty; users might feel uncomfortable using the application or browsing the website. Suppose the interface of the website or application is well-optimized from a UX perspective, and it is not overloaded with too many elements. In that case, users can think less about the following steps and focus more on the desired intention of the visit. UX designers and researchers must be aware of the system, how human memory works, and the limited capacity of human memory.

Each individual user of an application or website possesses a personalized memory capacity and employs it in a manner that is unique to their own circumstances. The user who frequents the website repeatedly is likely to exhibit distinct behavioral patterns compared to a newcomer. An easygoing user may behave in another way than a user under strain. The behavior of young individuals who engage with modern technologies on a daily basis may differ from that of older and less experienced individuals.

Since cognitive overload cannot be precisely measured, UX designers and researchers should strive to prevent design errors and acknowledge the limitations of human memory. The prominent errors include decision paralysis, excessive content, website actions, hard-to-locate pages, internal inconsistency overstimulation and ambiguous interface elements [1].

The text above indicates that user behavior on the website is strongly influenced by the limited amount of information retained in short-term memory.

This paper investigated the free recall of visually represented items.

The literature review summarized the previous research on short-term memory, list-length effect, serial position effect, and primacy and recency effect.

The primary research of this paper was an experiment focused on the recall of visually displayed information. The primary objective of the experiment was to ascertain the acquisition and forgetting of visually displayed information by recalling from short-term memory and reapplying investigations concerning the list-length effect, primacy effect, serial position effect, the effect of the information displayed in the form of the text versus symbol versus symbol with the text.

Research in this study revealed a different recall of various forms of visually displayed information and studied a dependency of list length effect on primacy and recency effect in immediate visual free-recall tasks.

2. Memory Research and Types of Memory

In 1885, Hermann Ebbinghaus conducted pioneering scientific research on memory, wherein he conducted experiments to explore the acquisition and forgetting of information [2]. In 1890, W. James introduced a distinction between primary memory, which temporarily retains a limited amount of information, and secondary memory, characterized as a relatively enduring storage that facilitates recall over longer durations, spanning hours, days, and even years [3]. Consensus among experts suggests the existence of a third component of memory known as sensory memory, which involves the initial processing of information received from sensory receptors [4]. These sensory receptors are divided into internal and external receptors. Internal receptors detect and react to internal changes within the body, such as variations in blood composition, chemical concentration, or the perception of pain. External receptors respond to stimuli originating outside the body, including odors, tastes, visual cues, auditory signals, temperature variations, pressure sensations, and distortions [5].

3. Short-Term Memory

Short-term memory is characterized as the memory employed during active thinking processes, often regarded as a subset of long-term memory utilized in the present moment [6]. Short-term memory possesses a notable constraint with a duration typically ranging from 10 to 30 seconds [7]. Short-term memory has a capacity to retain approximately 7 letters or numbers, fewer words, and even fewer sentences concurrently [8]. Well-organized information is retained more effectively in working memory compared to disorganized information [9].

Arranging items or objects into logical groups, known as chunking, enhances memorability. This is exemplified by the segmentation of a phone number into groups of three digits, which is typically easier to remember, and retrieve compared to a single uninterrupted sequence of numbers. The phenomenon of chunking has been observed across various cognitive processes [8].

In 1956, cognitive psychologist George A. Miller conducted one of the most renowned and extensively referenced studies in psychology, which also bears relevance to user behavior on websites. The pivotal discovery in his publication revealed that, under typical circumstances, an average individual can retain approximately 7 chunks in their short-term memory (with a range of plus or minus two depending on the specific circumstances) [8]. Miller did not determine how much information could be kept in each chunk. This study demonstrates that we can enhance the storage capacity of our short-term memory by organizing information into meaningful chunks. However, other studies, such as Ericsson's Acquisition of Memory Skill, propose fewer chunks than Miller's renowned "magical number seven" [10].

Findings from Jacobs’s research from 1887 can also be closely connected with designing the website. Jacob conducted research and found that individuals tend to recall a greater number of digits compared to letters. On average, the span for digits was 9.3 items, while for letters, it was 7.3. The recall span also varies based on age. In Jacob's experiments, 8-year-old participants could recall an average of 6.6 digits, whereas 19-year-old participants could recall an average of 8.6 digits [28].

In 1959, Peterson conducted a study that revealed a direct correlation between time delay and forgetting. The findings indicated that as the time delay increased, the rate of forgetting also increased. In this experiment, participants were able to recall 90% of the trigrams after a 3-second delay, but that percentage dropped significantly to just 5% after an 18-second delay [29].

Simon's experiments provided evidence that individuals have a reduced span when it comes to larger chunks, such as 8-word phrases, compared to smaller ones, such as one-syllable words. Through his research, he concluded that the optimal chunking size for numbers and letters is three. By organizing letters or numbers into meaningful groups, short-term memory can accommodate longer sequences more effectively [11].

In their extensively cited paper, researchers Baddeley and Hitch introduced an alternative model of short-term memory known as working memory. Unlike the notion of a single, unified construct, their model divided memory into multiple components, offering a more nuanced perspective [12].

Dempster's paper demonstrated that while human brains employ chunking as a means to enhance recall, the extent of this effect varies depending on the category, particularly for numbers. From early childhood through adulthood, it is observed that the majority of individuals tend to have a greater capacity for recalling digits compared to letters and words [13].

Sweller's research on the limitations of working memory builds upon Miller's information processing theories, providing further insights into how we should approach users' memory when constructing intricate systems like websites. The information and findings derived from Sweller's studies contribute to a more profound understanding of this aspect and its implications in system design [14].

4. Serial Position Effect

The phenomenon known as the Serial Position Effect refers to the tendency of individuals to recall the first and last items in a series more effectively than the middle items [15]. Ebbinghaus investigated this phenomenon and discovered that recall accuracy differs according to an item's position [16]. The role of item position in recall has three distinct components: strong performance in remembering early items (referred to as the Primacy Effect), diminished performance in recalling middle items, and strong performance in remembering late items (known as the Recency Effect).

Numerous studies have been published on primacy, recency, and the serial position effect of recall. The key findings relevant to website and application design are as follows:

The proportions of primacy and recency effects vary depending on the recall model. Research indicates that immediate free recall (where items can be recalled in any order) exhibits a significant recency effect and a minor primacy effect. On the other hand, immediate serial recall (where items must be recalled accurately from first to last) shows a weaker recency effect and a prominent primacy effect. [17].

The function of the serial position effect varies depending on the complexity of the memory span. In Kane's 2004 experiment, visually presented items were recalled in the forward direction. The findings suggest that, in complex tasks, the primacy effect is significantly reduced compared to the recency effect, in contrast to simple tasks where the primacy effect is more pronounced [26].

Murdock's study in 1962 revealed that the strength of the primacy effect is generally greater when items are presented at a slower pace, but diminishes when items are presented quickly.

Additionally, Murdock's findings from another experiment related to design indicated that longer presentation lists tend to reduce the primacy effect [18]. Murdock's experiment illustrated that the recency effect remains consistent regardless of the number of items on the studied list or the rate at which they were presented, as long as recall occurs immediately after testing [18], [19].

Glanzer and Cunitz presented the same list of words to two groups of participants. The first group was instructed to recall the items immediately after the presentation, while the second group was asked to recall the items after a delay of 30 seconds. Both groups were allowed to recall the items in any order. The researchers discovered that the items at the end of the list were only remembered if they were recalled first and tested immediately. However, the recency effect was prevented when there was a delay of 30 seconds before recall [20].

In an experiment conducted by Bjork, the recall activity was conducted in the presence of both preceding and following distracting activities, with an additional period of distracting activity before recall. Bjork's investigation demonstrated that the recency effect is substantially diminished when a distracting activity is introduced. Moreover, if the duration of the distracting activity exceeded 15 to 30 seconds, it completely negated the recency effect [21].

Numerous studies have examined the relationship between the serial position effect and the age of participants. Benjamin's study revealed that, on average, older participants tend to recall fewer and smaller chunks compared to their younger counterparts [22]. Other experiments demonstrated that the memory of older people is poorer [23] and less precise, and older people exhibit longer reaction times than younger people [24]. Griffin's study discovered that delayed retention varies across age groups, with older and younger adults exhibiting similar retention for primacy items. However, older adults generally experience decreased retention for middle and recency items in comparison [25].

5. Methodology of an Experiment

An experiment was executed on 9 various groups with different numbers of respondents. There was prepared total of 54 tests. 6 various tests were used in each group. These 6 tests contained two sets of pictures. One set was composed of 3 tests displaying items in the vertical form and the other 3 tests showing items in the horizontal format. Each set contained the items as the symbol, text, and symbol with the text.

Each of the nine groups faced different tests with different order and positions of the items in each test so that repeated items did not influence respondents in the same place. The length of each item for the whole experiment was between 4 and 7 letters so that it is consistent demand to remember and recall each item. Each item was carefully selected for each test, so there was no ambiguity, and it was easy to recognize. The choice of the items for the set was carefully made so that there was no affinity or similarity which could negatively affect the result of the experiment.

The tests were projected over 42 days in the Prague University of Economics and Business classes. There were two pilots before having an experiment, where the author tested the correctness of the whole process, duration of the experiment, and comprehensibility of the instructions and the experiment itself.

Before conducting the research, respondents were informed about the whole process of an experiment. The respondents could conduct the experiment on laptops or cell phone devices. After getting all the instructions concerning the experiment and the link on the prepared form, respondents answered the fundamental questions regarding demographics and information concerning their eyesight. The respondents were asked whether they had any eye defect diagnosed. A short test investigated respondents´ eyesight after filling in all essential information and answering the question about eye defects. Respondents had to recognize three pictures projected on the screen in front of the respondents. The respondents who claimed they had an eye defect were not automatically removed from the sample. Eliminating the respondents from the sample was done due to the eyesight test, and only the respondents who did not pass the eyesight test were put out from the sample and further analysis.

After finishing an eyesight test, the main experiment was conducted. The length of the test was contingent upon the quantity of items involved. There were either 5, 7, or 9 items in one test. For each item in the test, there were 2 seconds to be exposed. For 5 items, there was a time of exposition 10s; for 7 items, there was a time of exposition 14s; for 9 items, there was a time of exposition 18s. The exposition time of the items to the respondents was derived and applied according to the research from Murdock [18]. After showing the items for the intended period, the projected items were hidden, and respondents were asked to write the items they could recall. The respondents were asked to submit the form with their answers after being exposed to 6 tests.

The projection of the tests was conducted in the classes with closed jalousies and the lights switched off. The projection was executed with the standard projection devices with a resolution of 1920x1080. There were submitted a total of 4200 tests. After subsequent inspection of the tests, there were identified 197 errors. The majority of the errors were caused by syntax errors when respondents pasted the result into the form (I), by pasting multi-word answers (II), or by using synonyms (III). A minority of the errors were caused by mixing the parts of the form up. Errors I and II (40 cases) were corrected automatically. Error III (157 cases) was necessary to correct manually. 4140 tests were employed to further analysis.

6. Results

Free recall of visually represented items was examined with lists of 5, 7, and 9 items. A list of random symbols, text, and a combination of symbols and text was examined. The experiment hold at the Prague University of Economics and Business investigated students' recall. The experiment in this study revealed a different recall of various forms of visually displayed information and studied a dependency of list length effect on primacy and recency effect in immediate visual free-recall tasks.

The main aim of this part was to investigate how many items respondents can recall when 5, 7, or 9 items are visually interpreted. Table 1. shows the number of tests for each form of the test. In the tests consisting of 5 items, the respondents could recall 92% of items; in the tests consisting of 7 items, respondents could recall 81%; in the tests consisting of 9 items, it was 67%. Analysis of Variance ANOVA confirmed the alternative hypothesis that at least one pair of the mean values are not equal at the significant level of 0.00. The post hoc analysis reveals a significant disparity in the number of recalled items among the tests involving 5, 7, and 9 items. The highest number of items respondents could recall in 5-item tests while the lowest number of items the respondents could recall in 9-item tests.

Table 1. Statistics for all tests according to the number of symbols in tests

	5-symbols	7-symbols	9-symbols
No of tests	1416	1326	1398
No of man	996	825	783
No of female	414	495	609
No undergraduate	276	33	285
No of eye defect	141	150	177
Mnt Mean	8.28	7.27	6.06
Mnt SD	1.48	1.56	1.7

The mean value of recalled items in 9-item tests is significantly lower than 7 (5,97 – 6,15 at 95% confidence level). Respondents could recall about 6 items in 9-item tests. There was an applied One Sample t-Test to test the hypothesis that the mean value of the recall when 9 items are displayed is 7.

The result shows that the respondents could not recall the same amount of the items when 7 or 9 items were displayed. The mean value for the 7-item test is 5,67, and for the 9-item test is 6,03, so there is no significant increase in recalled items when 7 or 9-item tests were displayed. There was applied Two Sample t-Test (Mann-Whitney U Test).

The proportion of the respondents who could recall all 5 items in the 5-item test is 75,4%. The other hypothesis stating that more than 90% of the respondents can recall all 5 items when 5 items are displayed, was not confirmed. There was applied One Sample Proportion Test.

The proportion of the respondents who could recall all 7 items in the 7-item test is 27%. The hypothesis, which stated that more than 90% of the respondents can recall all 7 items when 7 items are displayed, was not confirmed. There was applied One Sample Proportion Test. The hypothesis says that the proportion of the respondents who could recall all 7 items in 7-item tests is the same as that of the respondents who could recall all 5 items in 5-item tests. There was a confirmed alternative hypothesis that the proportion of respondents who could recall all 7 items in 7-item tests is lower than that of respondents who could recall all 5 items in 5-item tests. The following hypothesis suggested that only less than half of the respondents can recall all 9 items. The alternative hypothesis was confirmed – the proportion of the respondents who could recall all 9 items is lower than 50 %. There was applied Two Sample Proportions Z-test and One Sample Proportion Test. A notable distinction was observed in the proportion of respondents, indicating a significant difference. The respondents who could recall all items (it was 73,45 % in 5-item tests, 27 % in 7-item tests, and 6,87 % in 9-item tests).

The serial position effect refers to the phenomenon wherein individuals tend to recall the first and last items in a series more effectively than the middle items (Colman, 2009). In other words, human memory is affected by the position of items in a sequence. The primacy and recency effects decompose the serial position effect into parts when primacy and recency effects differ under specific conditions. It is valuable to investigate these parts separately.

The main question of this part of the research is whether respondents can recall more items at the beginning and the end of the row than in the middle and how the number of items influences the recall in the test.

The research articles from the history concerning serial position effect investigated that intensity of primacy and recency effect varies for immediate free vs. immediate serial recall [17], complex vs. simple spans [26], a different speed of presented information [18], immediate recall vs. recall after 30 seconds delay [20], age of the respondents [22], [23], [24], [25], for related vs. unrelated words [27]. For this part of the study, the article investigating the dependency of primacy and recency effect on the list length is essential. The longer the list of items, the recency effect prevails primacy effect [18].

The main research question of the experiment related to the serial position effect (primacy & recency effect) investigated whether the respondents can recall more items from the beginning of the row and the end of the row than from the middle and how the number of the items in the test influences the recall.

The first hypothesis investigated whether respondents could recall more items from the beginning of the row than from the end or vice versa, regardless of the list length. There was applied One Sample Proportion Test and Two Sample Proportions Z-test.

There was investigated that the proportions of the respondents recalling the items from the beginning is higher than the proportions of the respondents recalling the items from the end (precisely the proportions of the respondents recalling the items from the beginning are 25,43 %, and the proportions of the respondents recalling the items from the end are 12,92 %). The results show that the primacy effect was higher than the recency effect regardless of the list length.

The primacy and recency effect was also explicitly investigated for 5, 7, or 9 items. The hypothesis suggested that the number of items displayed influences the primacy and recency effects; the increasing number of items in the test decreases the primacy effect and increases the recency effect. There was applied Two Sample Proportions Z-test.

There was not confirmed that the increasing number of the items in the test decreases the primacy effect and increases the recency effect. The results showed that only in 5-item tests the recency effect was more substantial than the primacy effect; nevertheless, the difference is not statistically significant (p=0,16).

The results also showed that increasing items significantly increases the primacy and recency effect. The proportions of the respondents who recalled the items from the middle are consistently lower than those who recalled the items from the beginning and end.

Regarding the hypothesis investigating the proportions of the recalls of the items at the beginning, in the middle, and at the end are the results following: the proportions of the respondents who could recall the items from the beginning in all tests is higher than the proportion of the respondents who could recall the items from the end. There was applied Two Sample Proportions Z-test.

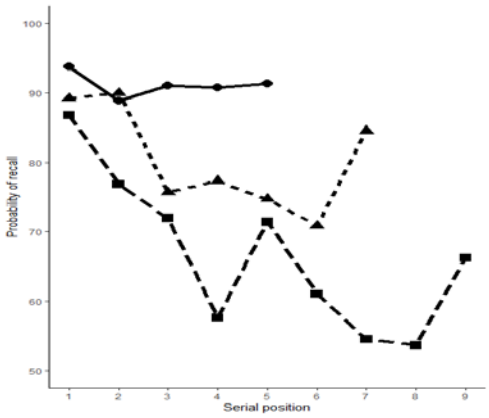

Figure 1. Serial Position Effect and Probability of Recall for 5, 7, 9 Items (5 - circles, 7 - triangles, 9 - squares)

The other part of the experiment investigated whether respondents recalled more items in horizontal or vertical representation. The hypothesis was that respondents recalled more items in horizontal than vertical representation. There was applied Two Sample t-Test (Mann-Whitney U Test).

The experiment results showed a slightly better recall in the horizontal representation of the items, but the difference is statistically insignificant (p=0,44).

Table 2. Horizontal versus vertical representation

	Horizontal	Vertical
No of tests	2070	2070
No of man	1302	1302
No of female	759	759
No undergraduate	297	297
No of eye defect	234	234
Mnt Mean	7.17	7.24
Mnt SD	1.92	1.74

The main research question, in the part of the experiment where the form of the item was tested, was if respondents recall more items in the form of the symbol, text, or symbol with the text. The hypothesis is that the respondents recall more items in the form of the symbol with the text than in the form when only the symbol or only text is displayed. There was applied Two Sample t-Test (Mann-Whitney U Test).

The experiment's findings showed that the amount of recalled items in symbols with text representation is statistically significantly higher than that of recalled items only in symbols or text representation. No statistically significant difference exists between the recalled items in symbol and text representation (p=1).

Table 3. Text/symbol/symbol with the text representation

	Symbol-Word	Symbol	Word
No of tests	1380	1380	1380
No of man	868	868	868
No of female	506	506	506
No undergraduate	198	198	198
No of eye defect	156	156	156
Mnt Mean	7.42	7.08	7.11
Mnt SD	1.69	1.94	1.84

The hypothesis in the section on demographics and other factors suggested that gender influences the number of recalled items. There was applied Two Sample t-Test (Mann-Whitney U Test). The results proved that men recalled a higher number of the items than women (at the confidence level of 0,05, p=0,0174).

The second hypothesis in this section investigated if age influences the number of recalled items. An analysis of the variance ANOVA test (Kruskal-Wallis test) and post hoc analysis was applied.

The results of the Kruskal-Wallis ANOVA test confirmed that at least one pair differs (at the confidence level of 0,05, p = 0,031). The following post hoc analysis confirmed the difference between the age group of 18-23 and 24-30. In all other applied tests (LSD, Bonferroni, HSD, Sheffer, Duncan), p-values were less than 0,05. Nevertheless, the results of this analysis are significantly influenced by the unequal representation of the respondents for each age group (especially for the border intervals less than 18 and more than 30).

7. Conclusion

Memory in the context of visually displayed information plays a significant role in user behavior and website design. This paper investigated 4 main phenomena connected with the free immediate recall visual representation of the information: list-length effect, serial position effect, horizontal versus vertical model of the information, and representation of the information in the form of the symbol, text, symbol with text.

Regarding the list-length effect, the primary findings indicate a substantial discrepancy in the number of recalled items among the tests involving 5, 7, and 9 items. The respondents could recall the highest number of items in 5-item tests and the lowest number in 9-item tests. Respondents could recall about 6 items in 9-item tests. The mean value for the 7-item test is 5,67, and for the 9-item test is 6,03, so there is no significant increase of recalled items when 7 or 9-item tests were displayed. There was a substantial difference between the proportion of respondents who could recall all items (it was 73,45% in 5-item tests, 27% in 7-item tests, and 6,87% in 9-item tests).

The study on the serial position effect aimed to determine whether participants demonstrate a higher level of recall for items located at the initial and final positions of a sequence in comparison to those situated in the middle. Additionally, the research sought to explore the influence exerted by the number of items included in the test on this effect. There was investigated that the proportions of the respondents recalling the items from the beginning is higher than those of the respondents recalling the items from the end. The results show that the primacy effect was higher than the recency effect regardless of the list length (5, 7, or 9 items tests).

The part of the research with horizontal versus vertical representation showed a slightly better recall in the horizontal model of the items, but the difference was not statistically significant.

The last part of the research, where text/symbol/symbol with the text representation was tested, showed that the amount of the recalled items in the symbol with the text representation is statistically significantly higher than the amount of the recalled items only in symbols or text representation. No statistically significant difference was observed in the number of recalled items between the symbol and text representations.

Memory in the context of visually displayed information plays a significant role in user behavior and website design. Wesites and computer programs frequently encounter an overwhelming array of design variables, components, shapes, and colors.

Users are required to remember and recall a multitude of forms, information, and content, which can pose a hindrance and contribute to user dissatisfaction, leading to their departure. Minimizing the cognitive load imposed on users, such as reducing the necessity to contemplate subsequent steps, design intricacies, or interface complexities, enables them to concentrate more effectively on their desired goals during their visits. User behavior on websites is intimately intertwined with the management of a restricted amount of information in short-term memory. This paper focuses on exploring and examining topics related to short-term memory, including the list-length effect, serial position effect, and representation of information in various formats. UX researchers and designers should possess an understanding of the limited capacity of human memory, how it functions, and how to design digital elements accordingly within the digital environment. The experiment's findings showed that the amount of the recalled items in symbols with the text representation is statistically significantly higher than the amount of the recalled items only in symbols or text representation. No statistically significant difference exists between the recalled items in symbol and text representation ($p=1$).

The findings in this paper should help UX researchers and designers to design websites and computer programs which will be more efficient and better optimized from the visual point of view.

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