The Effect of Using the Chunking Strategy in Memorizing Digits

Sajad Mowlaei[1, 2], Hadi Moradi[1, 2*], Javad Hatami[2], Majid Nili Ahmadabadi[1, 2]

[1]School of Electrical and Computer Eng., University of Tehran, Iran, [2]Psychology and education, University of Tehran, Iran

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Author contribution statement

s. Mowlaei is the leading researcher in this project. It was his mater thesis
H. Moradi is the first advisor of Sajad
J. Hatami was a counseling advisor for this project
M. Nili was a co-advisor of this work

Keywords

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Abstract

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The memorization of high volume of information is not possible unless it is organized or broken into pieces. This process of breaking information into smaller pieces, suitable for memorization, is called chunking. Although the research over memory capacity and memorization strategies started over 60 years ago, however, the knowledge of chunking is not yet complete. In this research, the effects of the use of chunking strategies in memorizing sequences of digits are measured on the performance of individuals through a computerized assignment. The computer assignment is composed of two modes. In the first mode, subjects can use their own chunking strategy in memorizing sequences of digits. In the second mode, the subjects are guided to use a specific chunking strategy by grouping the digits on the screen. The assignment was conducted on 35 subjects, 17 female and 18 male subjects. There was a statistically significant difference between the performances of participants using different chunking strategies. This finding suggests that the most suitable chunking strategy varies across the subjects. The results also show that, people generally achieve lower performance when using their own chunking approach and, teaching the best chunking strategy may improve their overall performance. These findings play a key role in the design of interactive human-machine interfaces and cognitive games.

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Although the study did not include intervention, so there was no need for a committee approval, we informed the subjects about the purpose of the study and gave them the option to exit the study at anytime they wanted. Also, we got the ethical approval from the ethics committee of the school of psychology and education, University of Tehran.

Title: The Effect of Using Chunking Strategies in Memorizing Digits.

Sajad Mowalei[1], Hadi Moradi[1,2], Javad Hatami[3], Majid Nili Ahmadabadi[1]

[1] Cognitive systems Lab., School of Electrical and Computer Engineering, College of Engineering, University of Tehran, Tehran, Iran

[2]Intelligent Systems Research Institute, SKKU, Suwon, South Korea

[3]School of Psychology and Education, University of Tehran, Tehran, Iran

*** Correspondence:**
Hadi Moradi
moradih@ut.ac.ir

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Abstract:

The memorization of high volume of information is not possible unless it is organized or broken into pieces. This process of breaking information into smaller pieces, suitable for memorization, is called chunking. Although the research on memory capacity and memorization strategies started over 60 years ago, however, the knowledge of chunking is not yet complete. In this research, the effects of the use of chunking strategies in memorizing sequences of digits are measured on the performance of individuals through a computerized assignment. The computer assignment is composed of two modes. In the first mode, subjects can use their own chunking strategy in memorizing sequences of digits. In the second mode, the subjects are guided to use a specific chunking strategy by grouping the digits on the screen. The assignment was conducted on 35 participants, 17 female and 18 male participants. The obtained data was analyzed, and the result show that there was a statistically significant difference between the performances of participants using different chunking strategies. The finding suggests that the most suitable chunking strategy varies across the subjects. The results also show that, people generally achieve lower performance when using their own chunking approach and, teaching them chunking strategies may improve their overall performance. These findings play a key role in the design of interactive human-machine interfaces and cognitive games.

1 - Introduction:

For many years, one of the main research trends in education, psychology, and specifically in educational design was to understand the capacities and limitations of the human mind to develop strategies that facilitate and strengthen the learning process (Hris Lawrence, 2017). In parallel, in the marketing and advertisement sectors, there have been studies to learn how customers think in order to find ways to find more effective and efficient methods for attracting their attention and altering their perceptions (Hris Lawrence, 2017).

On the other hand, the design and development of attractive computer games need to consider the mental perception and acceptance of these games. That is why if the cognitive stimulus rate is high, i.e. there is a huge variety of environments, information, tasks, and decisions to be made, players become confused and stressed. In general, these situations are not considered as pleasant experiences (Hris Lawrence, 2017). To avoid this, strategies must be used to help set up cognitive stimulus rates according to a player's cognitive state and abilities; including memorization capacity, which plays a key role in cognitive processes.

There are cognitive theories, such as the Cognitive Load Theory (CLT), which supports the fact that a game should consider the cognitive state and abilities of its players. CLT, with its different categorizations (Paas, Renkl, and Sweller 2003), suggests that there is a limited human brain capacity for processing information (Sweller, 1999). For instance, Sweller and his colleagues (Van Merriënboer and Sweller, 2005) have suggested that the human cognitive structure consists of Working Memory (WM) and Long-Term Memory (LTM). WM is responsible for selective processing of information obtained by human senses, such as audio and visual, and has very limited duration and capacity. WM is used to understand the received information, in order to make more complex concepts called "schema" (Sweller 2017). Schemas are stored in and retrieved from LTM, which, unlike the working memory, can contain vast numbers of schemas.

To use WM more efficiently, people use different strategies, such as chunking (Cockcroft, 2015). In this strategy, people divide the information into smaller pieces and then remember them. This allows them to remember long sets of information, which may not be possible to remember them otherwise. To better understand the chunking mechanism, there have been several studies looking into the chunking process, e.g. Tulving and Patkau (1962) and Chase and Simon, (1973). However, to the best of our knowledge, there has been limited research on how people chunk a sequence of items. Furthermore, there is no comparative study on the effectiveness of different chunking approaches.

In this research, we focus on chunking strategies, specifically for numerical strings. Numerical strings, such as phone numbers, exist in everyday life. Unlike the existing literature that focuses on chunking at the population level, the aim of this research is to see if there are major individual differences in chunking strategies and, to check if we can improve the subjects' performance by imposing an alternative chunking. We found that there was a statistically significant difference between the performances of participants using different chunking strategies. The results also show that, people generally achieve lower performance when using their own chunking approach and, teaching the best chunking strategy may improve their overall performance. These findings can help to improve the design of games, especially cognitive games, and to help people improve their performance in their daily life.

2- Literature Review

2-1- Chunking and its types:

In general definition, chunking is the process through which a person compresses, reorganizes, or groups information. Chunking is one of the most widely known methods of increasing the data stored in memory. Chunking can occur by two different methods. The first method is through strategic organization based on a prior knowledge while in the second method, grouping is done based on perceptual features. As an example of the first method, a hard to read and remember word like "AWOLNASAMIA" is broken into a group of smaller chunks; such as AWOL, NASA, and MIA, which are previously known abbreviations. In the second method, which is more common in visual stimuli, one can form groups based on similarity or degree of proximity. For example, people group shapes by their colors and then memorize them (Gilchrist, 2015).

The first recorded definition of chunking process is given by William James in his Principles of Psychology book (James, 1890). However, chunking is mostly known based on George Miller's article "Magic Number Seven or Minus Two" (Miller, 1956). Miller reviewed several studies that examined the limitations of the memory capacity to immediate recall of items. It is shown that a normal person can store 7 ± 2 groups of information. Miller also observed that if information stored in appropriate units, i.e. chunks, the amount of information that can be recalled in immediate memory increases. This occurs because of increasing meaning through chunking information (Tulving and Patkau,1962; Chase and Simon, 1973). It should be mentioned that the number of information that can remain in short-term memory is limited to four items or less (Cowan 2001; Mathy and Feldman 2012).

In many published studies, it is suggested that the items that are in the same chunk are heavily compacted. Furthermore, items in one chuck are expected to have stronger link to each other than items in different chunks (Oberauer and Bialkova 2009; Mathy and Feldman 2012). These differences show themselves in recall phase in terms of Response Time (RT) and the accuracy of response. In the first case, response to the items that are part of the same chunk are to be more accurate, i.e. less error rate, than items that are separated across chunks. Based on this assumption, it is possible to calculate the Transitional Error Probabilities (TEP) to adjust the items to determine the current boundaries of the chunks (Chase and Simon 1973; Johnson 1966). Ideally, the probability of a transition error should increase by approaching the boundary of chunks. In the context of RT, the same assumptions can also be made. That is, the response time between the recall of items, when approaching the boundary between the two chunks, would increase. This is because these adjacent items are more related to each other than items in different chunks (Broadbent 1975; Anderson and Matessa 1997).

The mentioned phenomena are usually useful in memorizing information that are pre-structured; such as information that are bundled together in pairs. However, it is not clear what would happen when the information does not have a specific structure. Interestingly, the methods used to evaluate the chunking of verbal information, i.e. information that do not have a structure, assume the same phenomena of paired information. Given the fact that the likelihood of the items bounded together being part of a chunk is greater than the items that are in separate chunks, it can be said that the information retrieved together should be part of a same chunk (Anderson and Matessa 1997).

This hypothesis, at first, was used by Tulving and Patkau in their work addressing the chunking methods (Tulving and Patkau 1962). Based on this hypothesis, information that is recalled word by word is part of the same chunk. They characterized the boundaries of chunks based on errors or long pause in the information recall phase. They modeled the chunking process in short-term memory by introducing the chunk access and the degree of completion, which approximates the number and size of the stored chunks. Access to short-term memory is measured by the number of independent units or groups, such as sentences, which are remembered in free recall. Completion is evaluated based on the ratio of items that are recalled. For instance, consider a participant reads a random set of sentences such as "The man ordered a scone and waited for his coffee". Suppose the participant remembers "The man ordered a scone waited coffee" only. The rate of completion is 64 %, because seven of the eleven words are remembered. This can be considered as one of the ways to chunking, in which the recalled phrase would result in a measurement of three separate chunks. The items are properly recalled in correct order, but the failure to remember all the word, i.e. “and” and “for his”, makes boundary of chunks (Tulving and Patkanu1962).

Toward categorizing different chunking approaches, Gilchard and Kwan categorized chunking into spontaneous chunking and experimentally manipulated chunking categories (Ramachandran, 2012). Spontaneous chunking is referred to the case in which no specific chunking method is presented, and a subject decides the method spontaneously. In contrast, in experimentally manipulated chunking, subjects are directed to a specific chunking method through different medium.

2-2- A review of research on spontaneous chunking

Cranel and Parish studied the range and size of words, number, and letters in two forms of "auditory presentation" and "oral recall". The authors reported that the most common chunking of six digit sequences was the use of 3 digit groups, i.e. two chunks of three digits each (Crannell and Parrish 1957).

Heron conducted a study in which eight digits, as phone numbers, dialed with a rotary telephone, i.e. the old phone devices. Most people divided these numbers into two groups of four digits, and people who chunked in this way made fever errors than others (Heron 1962).

Thorpe and Rowland investigated chunks in 7, 8, and 9-digit chunks by examining the pauses, rhythms, sound songs, and format in free recall. In this case, the most commonly used chunk size was four (Thorpe and Rowland 1965).

In 1998, Fendrich and his colleagues showed that people chunk numbers in groups as small as two digits, in which they pause after the second digit (Fendrich 1998). Interestingly, when the strings were three digits, there were no pause; meaning that groups of three digits are not divided (Fendrich, Healy, and Bourne 1991). This difference in chunking three and four-digit numbers indicates that the boundary of the piece depends on the length of the string.

2-3- A review of studies conducted in experimentally manipulated chunking

Klemmer asked participants to perform an error check task on a set of numbers. Using empty spaces between digits, the chunking from one to ten digits was made, and the speed of error checking was higher for three or four-digit chunks (Klemmer 1959).

Severin and Rigby (1963) displayed seven-digit numbers separated by a dark line in four different patterns: 4-3, 3-3-1, 3-2-2, and 2-2-2-1 digits patterns. Participants read numbers of all four groups and repeated them aloud. The error rate for 4-3 pattern (three digits, dark line, four places) was lower than other patterns (Severin and Rigby 1963). Other studies also have shown that it is faster to memorize if chunking was three or four digits (Klemmer and Stocker 1974; Klemmer 1969).

Mayzner and Gabriel conducted a study in which 12 digits were represented as different matrices. Immediate recall of the numbers was better where numbers displayed in 6 columns by 2 rows matrix. And second best representation was in the form of three by four matrix (Mayzner and Gabriel 1963).

It should be mentioned that in contrast to the effects of chunking found in all other studies, Conrad and Hull did not observe any effect of chunking in memorizing vertical lists of digits (Conrad and Hull 1967).

Bower and Winsenz showed that chunking numbers into same length chunks eases memorization of the chunks into long-term memory (Bower and Winsenz 1969). In contrast, if the chunk size changes over different trials, no improvement in long-term memorization is achieved.

In a related study, Stadler (1993) applied the Serial Reaction Time (SRT) task proposed by Nissen and Bullemer (1987). In the STR task, a star sign moves between four different locations on a computer screen and participants should push the key below star sign as fast as possible. In one setup, Stadler showed a 10-item sequence several times to the participants, while he used uniform pauses after each location. In another setup, there were random pauses, or no pause after each location. He showed that participants were able to better memorize in the first setup compared to the second setup. This finding was interpreted that pause can cause chunking of items and facilitated learning and memorization.

Koch and Hoffman (2000) used the pattern of a response sequence with a SRT task. A pattern consists of three items created within a sequence. For instance, in 123321456654, 123 and its reverse and 456 and its reverse create a pattern. The RT pattern showed a distinct pause after the third response of participants, meaning that the triplets were chunked. Similarly, Bower and Winsenz study (Bower and Winzenz 1969) suggested that consistent grouping unitizes the chunks.

It should be mentioned that none of these studies focused on comparing different chunking methods. Furthermore, they did not consider the impact of trying other chunking methods on the memorization performance. In this study we study these issues.

3 - Method

3-1- Participants

35 volunteers (17 women and 18 men) participated in the study. All of them were students of University of Tehran. The mean age of the participants was 24.7 years and the standard deviation was 2.1 (range 20-27). Due to the dependence of working memory capacity on age, the age range of individuals was limited by the Cockcroft research charts (Cockcroft 2015).

3-2 Procedure

To evaluate the different methods of numerical strings' chunking, a computer test was designed. In this test, strings[1] of length 6, 8, 9, and 10 digits were used. The smaller strands were removed from the test because they were too simple to have any impact on the performance of individuals. The strings longer than 10 digits were also removed, since they were too difficult to be memorized by most of the participants.

The designed test involved two phases. The first phase consisted of 17 trials and in each trial a string of numbers was visually represented with a same spatial

1 For the sake of easier presentation, string and numerical strings are used interchangeably in this article.

distance between the numbers, i.e. no chunking was imposed. Thus, the participants had the option to chunk string into any desired groups. For example, the string 7 2 6 4 1 3 can be stored in any format, such as:

- Seven, two, six, four, one, three
- Seventy two, sixty four, thirteen
- Seven thousand two hundred and sixty four, thirteen

The second phase, which was conducted after the first phase, consisted of 35 trials. In this phase, to implicitly impose chunking, the strings were chunked, and the chunks were separated by dark lines. For example, the string 7 2 6 4 1 3 was presented as 72-64-13 to push the participants to break it into "seventy-two, sixty-four, and thirteen”. Below are two images of the strings of the first and second phases (Fig. 1).

Figure 1: An example of first phase on the left and second phase on the right

At each trial, at first a string was displayed to each participant for a period of time which depended on the given string length. In this study, 1.6 seconds was allocated to each digit, which was set after a pilot run of the computer task and based on the feedbacks from the participants. Thus, for example, a 4-digit string was displayed for 6.4 seconds. After this period, the string was disappeared, and a blank screen was shown for 4 seconds. Then, a microphone icon was appeared and the participant had to recall the string and utter it loudly to be recorded. The participants' voices were analyzed after the test.

The following four steps are presented in Fig. 2.

Figure 2: Test steps: from top-left to bottom-left, the string of numbers is displayed, the string disappears for a 4 second period, a microphone icon appears, and the subject recalls the string and utters it to be recorded. Finally, the participant ranks the confidence in his/her answer.

At the end, a question was asked about the participant's strategy. In this section, the participant had to choose the strategies he/she had used to remember the strings and rank the effectiveness of each strategy. Also, the participants could explain their strategies, if not included in the default set; see (Figure 3).

Figure 3: Strategy question

The total test duration was about 25 minutes and the cognitive load was too much for one sitting. Thus, after the 17 and 34 trials, the participants had to rest for a few minutes before continuing to the next trial.

4 - Results

In phase one, the participants were asked to remember a sequence of numbers separated by a single space. They were supposed to chunk, remember, and recall the strings in any way they want. Fig. 4 shows the performance of one of the participants in this phase. This participant was able to answer all 6 and 8-digit strings. However, his performance in strings of lengths 9 and 10 were about 75% and 30%, respectively.

Figure 4: The performance of a sample participant in phase one test

In the second phase, for each string, different chunking formats were imposed on the participants. For a string of length 6, single, double, and triple digit chunks were imposed. For a string of length 8, single, double, and quadruple digit chunks were imposed. For a string of length 9, single and triple digit chunks were imposed. And for the strings of length 10, single, double, and quintuple digit chunks were imposed on the participants. The single chunk means that each chunk contains only one number. For example, 4-5-2-8-3-2-9 is in single chunk format and the participants pushed to memorize four, five, two, eight, three, two, and nine. Similarly, 49-26-31 is a double-digit chunk in which a participant had to remember forty-nine, twenty-six, and thirty-one. Fig. 5 shows the performance of a sample participant in this phase.

Figure 5: The performance, represented by the vertical axis, of a sample participant in phase two

Fig. 6 is a combination of the two above diagrams. That is, the performance in phase 1 and the best performance in phase 2 are shown side by side for each string length. In other words, this diagram compares the maximum performance obtained by imposing chunking in the second phase with the performance of free-will chunking in the first phase. It can be seen that the imposed strategy makes the participant to gain higher performance.

Figure 6: A comparison of the performance, shown along the horizontal axis, of the sample subject in figures 4 and 5 in phase one and phase two. The performance is better when the subject is guided in 9 and 10-digit cases.

4-1- The analysis of the results

The participants in the first phase chunked the strings in a variety of ways. For example, 74%, 21%, and 5% of the subjects remembered six-digit strings by three dual-digit, two triple-digit chunks, and six single-digit chunks, respectively. In Fig. 9, the dispersion of different strategies over all subjects is specified for each string length. In this chart, the horizontal axis specifies the chunking style. For example, single means chunking with length of one digit, and dual & triple means chunking includes two and three-digit chunks.

Figure 7: The application of different strategies in phase one of the test. Interestingly, the use of chunking into 2 and 3-digit chunks is heavily used by the participants when the number of digits goes beyond 6.

Fig. 8 is similar to Fig. 7, except that only the correct answers are counted.

Figure 8: The correct answers in each chunking strategy in phase one. The higher performance of using 2 & 3-digit chunking methods, in higher than 6-digit strings, is clear in these diagrams.

4-2: The first and the second hypothesis

The first hypothesis of this study is that each person has different performances when using different chunking strategies for a string. To evaluate this hypothesis, the average of the highest and the lowest performances of all subjects, in phase two across the chunking strategies for each given string length, are calculated. Then, the differences between these two values were checked using t-test. It should be mentioned that if a string is easy for a person, with any strategy he/she can remember it well. Also, if a string is too hard, regardless of the strategy, the performance would not be good. However, the strings with medium difficulty would show the difference among the strategies. That is why only the string of length 6, 8, 9, and 10 digits are used in this study.

In Table 1, the results of the paired t-test on the best and the worst performances in the second phase are presented. For example, for 8-digit strings, the average highest and the average lowest performances of the subjects were 55%, and 39% respectively and the difference is statistically significant with $p<0.0001$.

Furthermore, repeated measure ANOVA was conducted to determine if there is a significance difference between different chunking strategies for each individual. The analysis shows that the null hypothesis, i.e. there is no difference between different chunking strategies for each participant, is rejected. The results are presented in Table 2.

The second hypothesis is the lack of awareness of individuals about the optimal chunking strategy they can apply for each string length. In the first phase, in which the participants were chunking arbitrarily, some followed a single strategy for all strings of the same length while others used different chunking strategies. The mean performance of the participants in the first phase was compared with the highest performance among all the strategies in the second phase, using the t-test. In other words, it was checked if the subjects could improve their performance using a chunking that differs from their own chunking strategy. In Table 3, this analysis is summarized.

Fig. 9 shows that the performance of the participants was better, in 8, 9, and 10-digit strings when they followed the chunking strategy imposed in phase 2. In the case of short digit strings, i.e. 6-digit strings, the performance is the same in the two phases since it is too easy, and any chunking method is good to be used.

Figure 9: The number of subjects, who performed better in each phase, i.e. P1 and P2, for different string lengths.

Fig. 10 compares the performance of participants whose phase 1 strategy matched the proposed chunking strategy in the second phase with those whose phase 1 strategy was different than the proposed chunking strategy in phase 2. The performance of the latter was better than the former. In other words, there are more people who are not aware of the best chunking strategy they may employ, i.e. the orange bars, versus the people who used their own chunking strategy in both phases and performed well in both, i.e. the blue bars.

Figure 10: Blue bars show the number of subjects having their best performance, in phase 2, when the proposed strategy matched their own strategy used in phase 1. Orange bars represent the number of subjects whose best performance, in the 2nd phase, achieved when the proposed strategy was different from their own strategy that they used in the first phase.

4-3: The effect of string length and chunking strategy on performance

Here we show the relation between the chunking strategy and the string length in the memorization performance. To do this, the Generalized Linear Model (GLM) approach is used to model the performance of individuals based on the chunking strategies and the strings lengths. The modeling is done on strings with length of 8 and 10 and single and double-digit chunking strategies. Chunking into four and five digits was excluded from the modeling due to their lack of uniformity. Also, the strings of length 9 were set aside, because they have only triple chunking and cannot be compared to the length of other strings. The GLM model was constructed setting B0 = 5.16, B1 = -0.65, and B2 = 0.55. To evaluate the importance of each parameter, i.e. the chunking strategy and the string length, the likelihood ratio test was used. The results show a significant effect of the chunking strategy on the performance of individuals ($p = 0.0196$).

5- Conclusions and Future work

Working memory limitation is one of the key factors that human interaction system designers should take into account. Individuals use different methods, such as chunking, to increase the performance of their working memory. In this research, the performance of individuals was investigated based on various chunking methods of strings of digits.

This research had two findings. The first one was that, the performance of individuals using different chunking strategies, such as chunking by groups of two or three digits, was very different from each other. The second finding was that, people may not use the optimal chunking strategy, and suggesting such strategy may improve their performance. A two-phase test was carried out. In the first phase, the participants chunked the strings based on their own preference/habit, and in the second phase a chunking strategy was imposed on them. The results revealed that a large group of participants performed better when they employed one of the imposed strategies; that differed from their own one.

To examine the underlying cognitive processes involved in chunking, we should consider methods that allow further examination of the internal cognitive processes. These methods include neurophysiological recording and computational cognitive models. For instance, fMRI can be used to determine the regions and the amount of activity in each region, when different chunking methods are used.

In the next step, we will check if the recall improvement by using the imposed chunking method results in lower cognitive load. In addition, it is of high practical importance to devise a convenient way to teach the best chunking method to everyone.

Ethical approval

This work is approved by the ethics committee of the school of psychology and education, university of Tehran. Also, written consent form was collected from participants and they were informed about the research goal and methodology.

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Table 1: Analysis of Phase two data

String length	P	CI
6	0.021	[0.21,0.01]
8	0.000	[0.55,0.39]
9	0.000	[0.41,0.18]
10	0.000	[0.68,0.40]

Table 2: Repeated measure ANOVA results to evaluate the effect of strategies

String length	F-Statistic	p value	null hypothesis
8	1.263	$p < 0.05$	Rejected
9	3.099	$p < 0.05$	Rejected
10	3.01	$p < 0.05$	Rejected

Table 3: Comparison of Phase One and Two results

String length	P	CI
6	0.006	[0.25,0.04]
8	0.000	[0.37,0.17]
9	0.130	[0.25,-0.03]
10	0.000	[0.54,0.26]

Figure 1.JPEG

Figure 2.JPEG

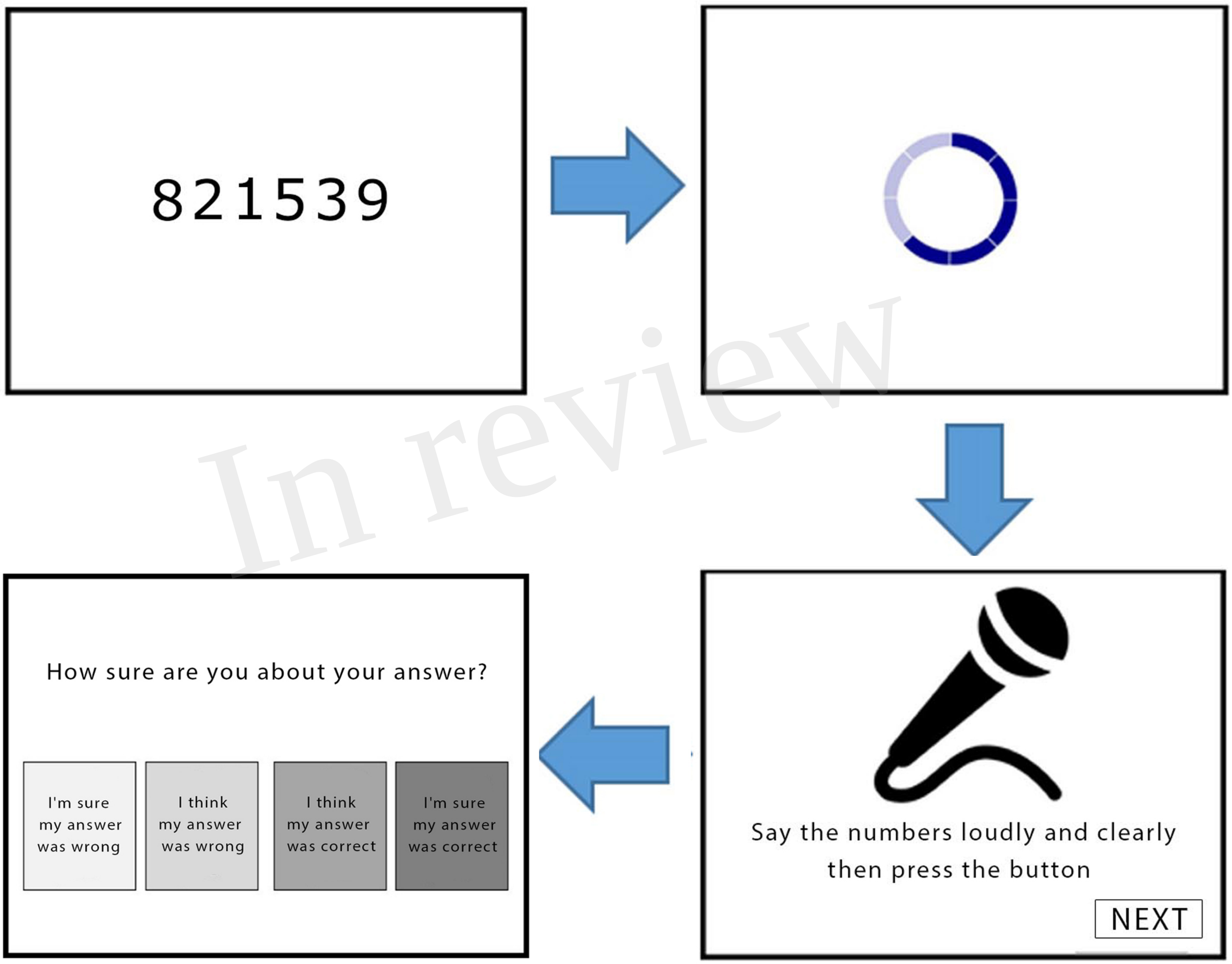
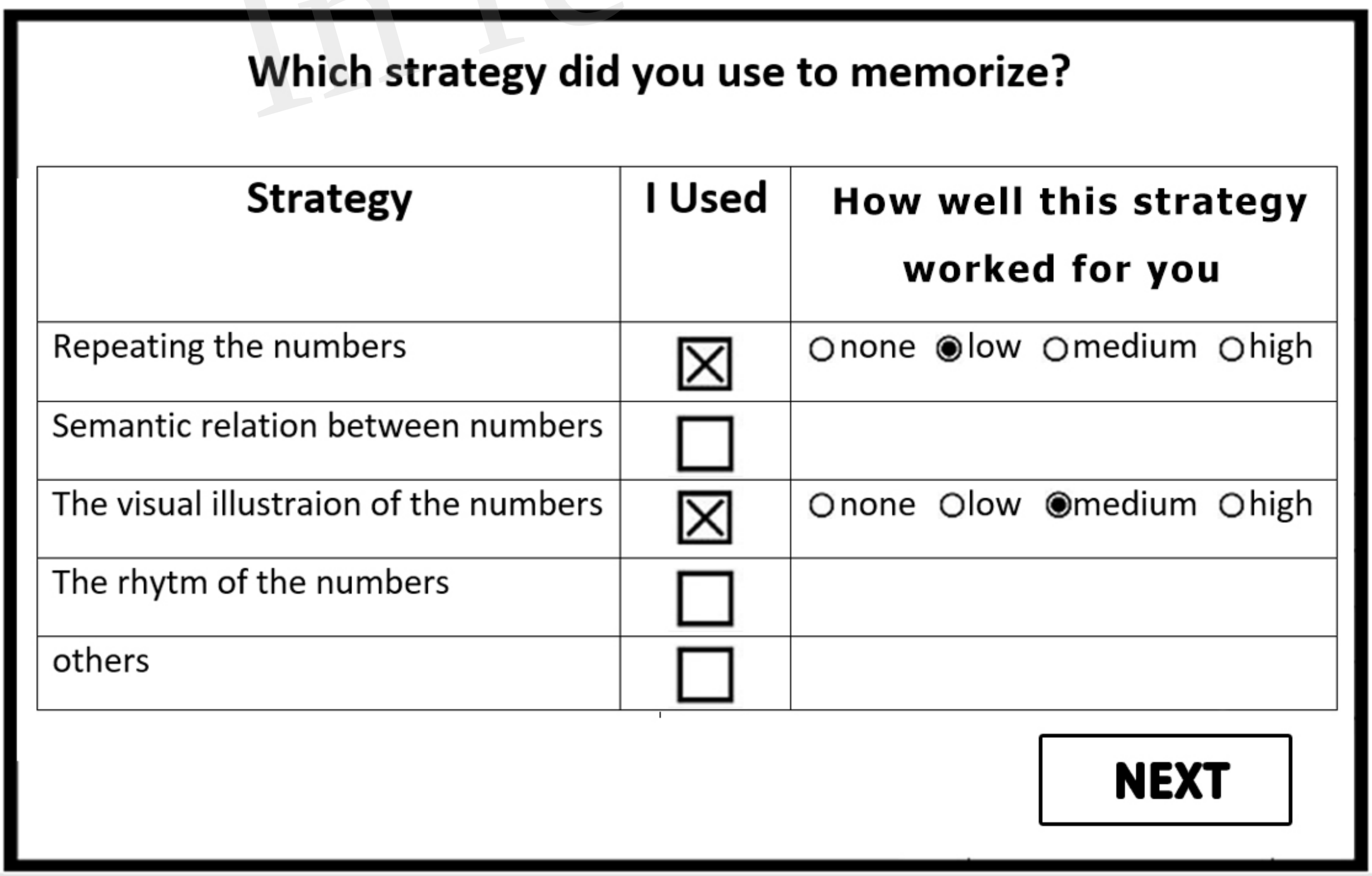


Figure 3.JPEG

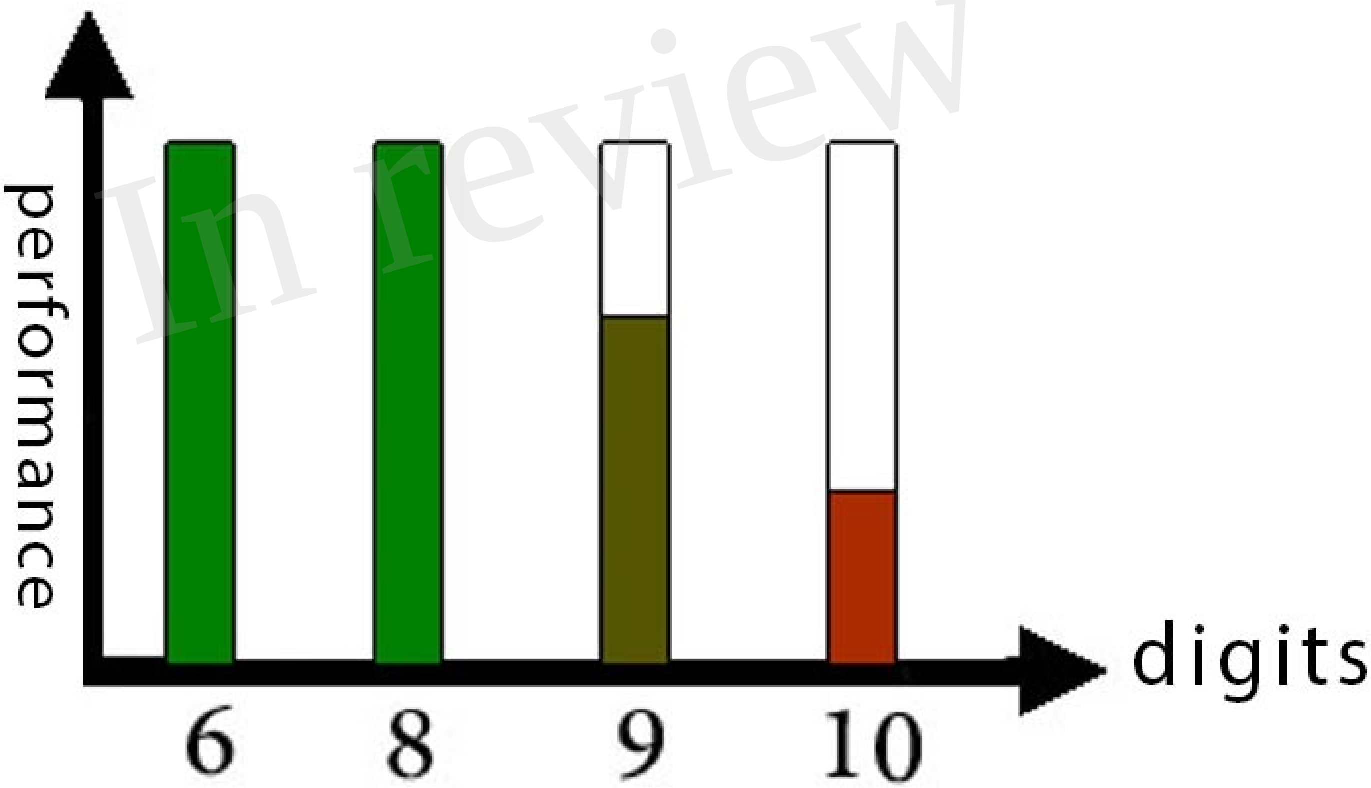


Which strategy did you use to memorize?

Strategy	I Used	How well this strategy worked for you
Repeating the numbers	☒	○none ◉low ○medium ○high
Semantic relation between numbers	☐	
The visual illustraion of the numbers	☒	○none ○low ◉medium ○high
The rhytm of the numbers	☐	
others	☐	

NEXT

Figure 4.JPEG



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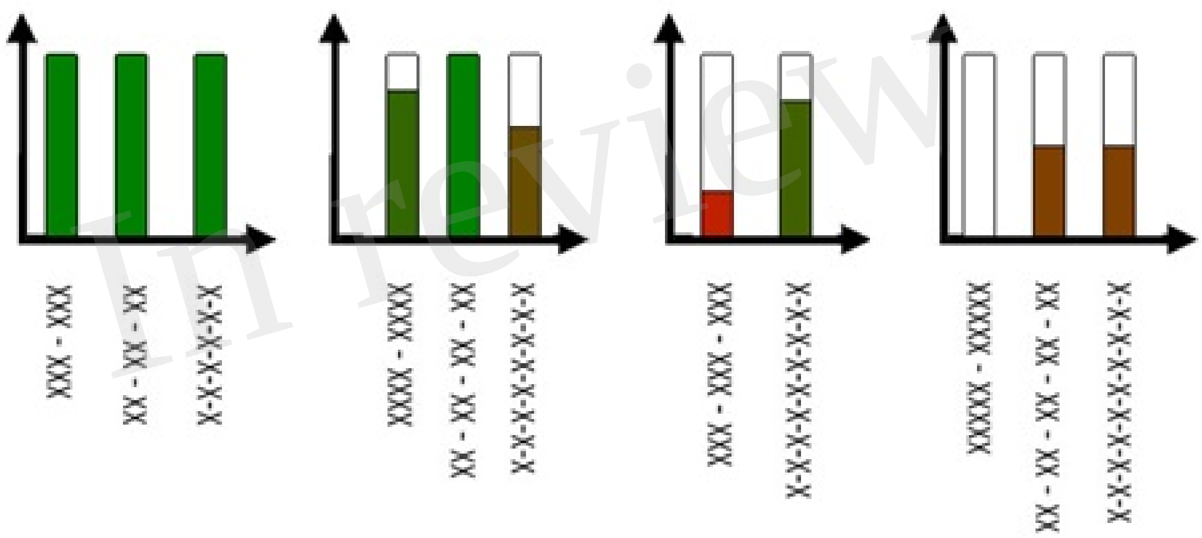

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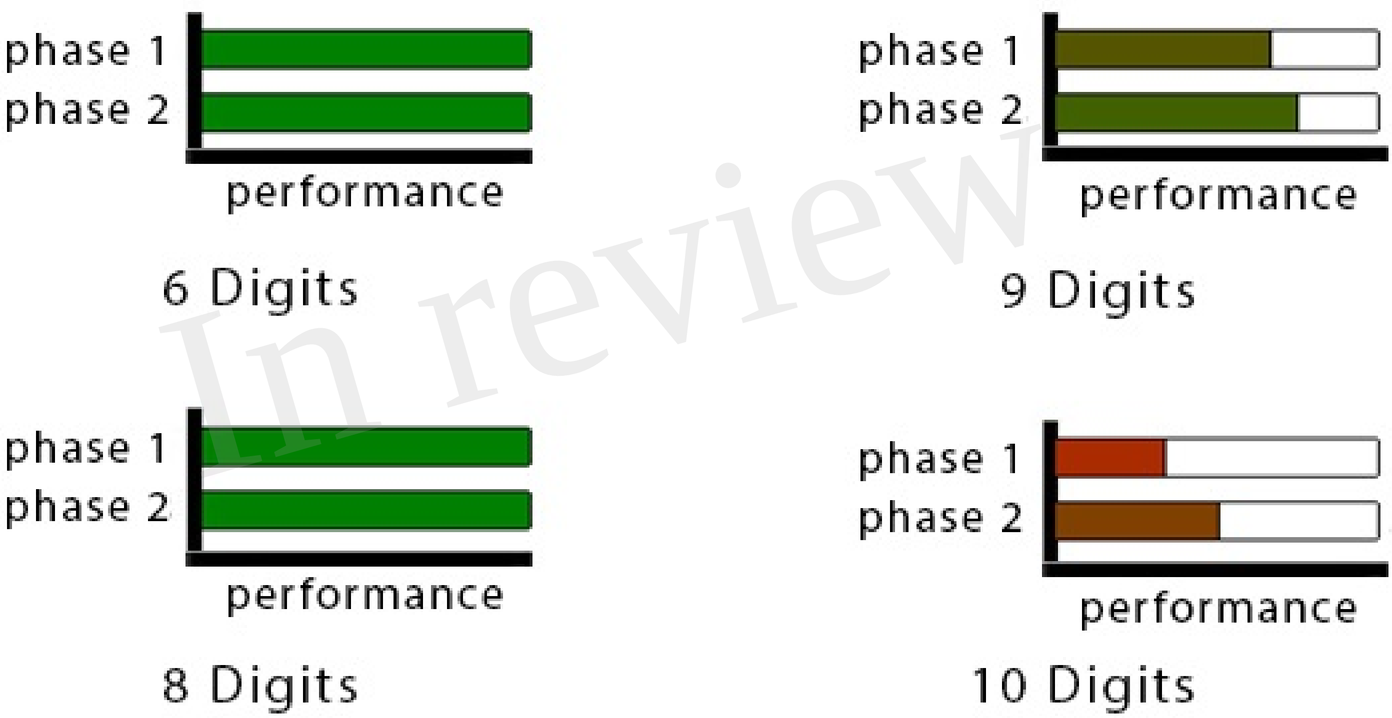

Figure 7.JPEG

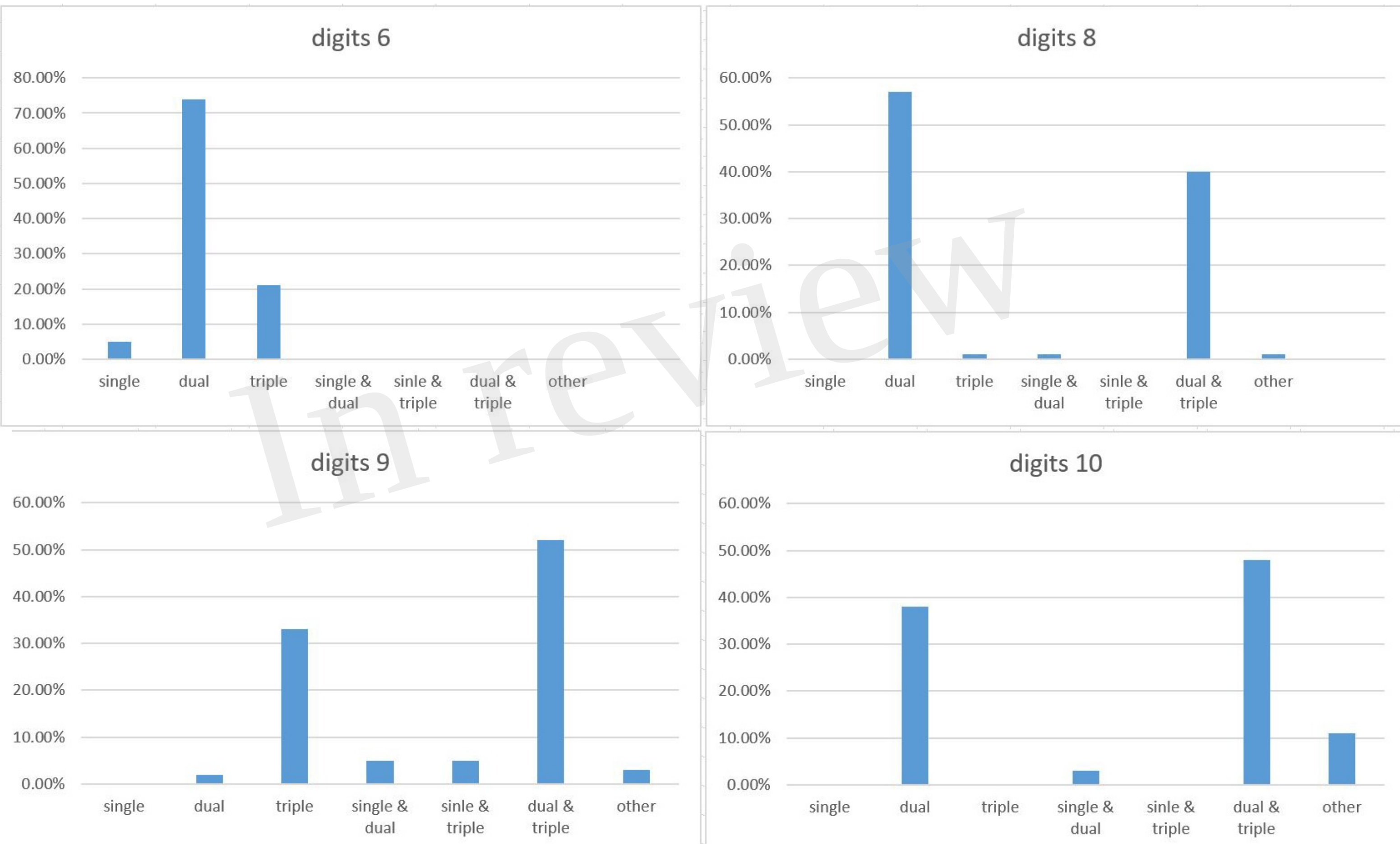

Figure 8.JPEG

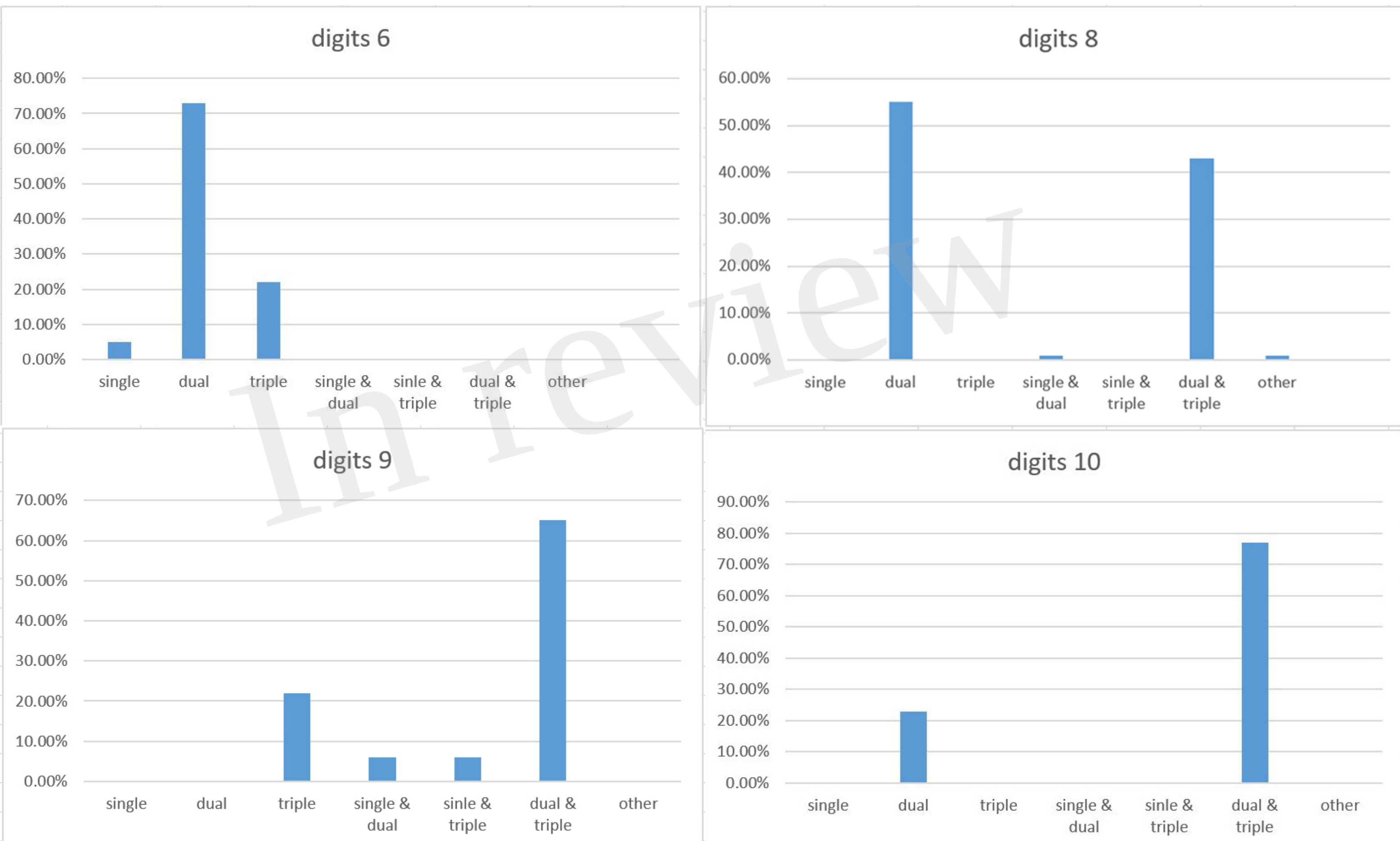

Figure 9.JPEG

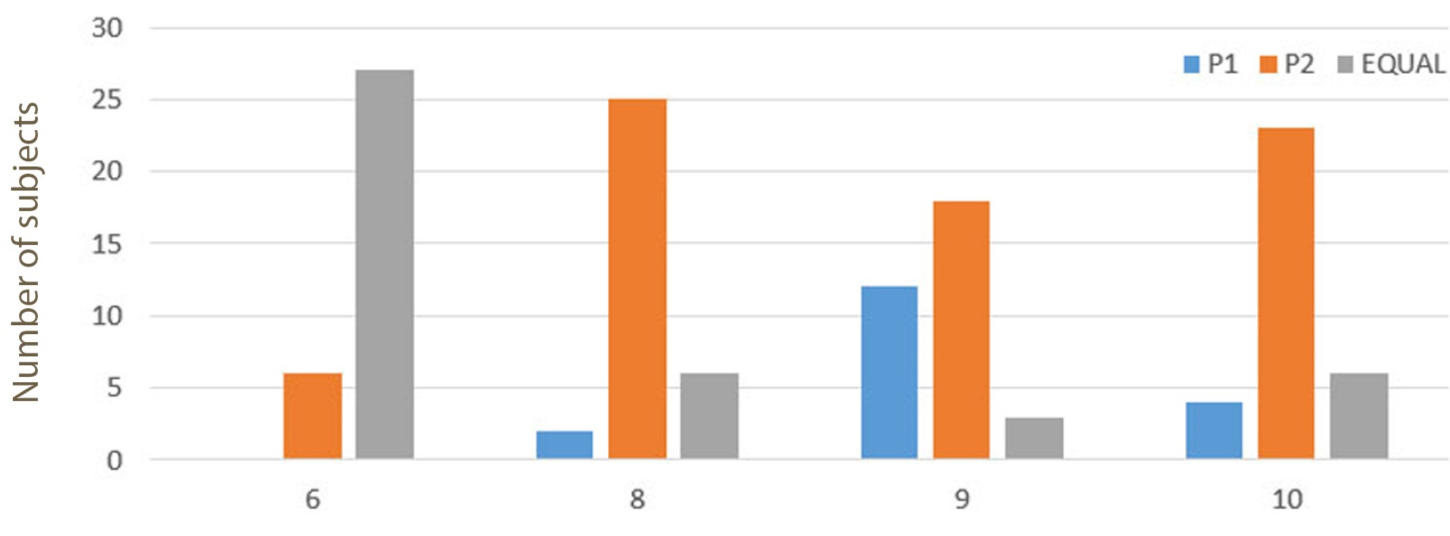

Figure 10.JPEG