The Influence of Vibrotactile Cues in a Short-term Memory Cognitive Exercise

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ABSTRACT
This paper describes the research on the influence of vibrotactile cues in a short-term memory cognitive exercise. The goal of this research is to see if vibrotactile stimuli could be a beneficial aid in a cognitive exercise. In this research participants were asked to perform a cognitive exercise in which the goal was to remember as many of the 20 images that were shown to them in 3 second intervals, as possible. 10 of these images would be accompanied by vibrotactile stimuli from a wearable vibrotactile device on their arm. After the images were shown the participants had 60 seconds to enter in as many as they could remember. While the results of this experiment show an increase in performance when images are presented with a vibrotactile stimulus compared to those without, the difference between the images with and without vibrotactile stimuli is not statistically significant. However, data does indicates a trend between images with vibrotactile stimuli and overall performance. Due to the relatively small scale of this experiment, we suggest further research in order to replicate and expand on the findings of this study.

KEYWORDS
Tactile Feedback, Short-Term Memory, Retention, Haptic Feedback, Cognitive Exercise, Brain Training, Vibrotactile Stimuli

1. INTRODUCTION
Memory ageing can start as early as young adulthood [10]. As people get older cognitive functions start to decline and both short- and long-term memory are affected. With the increasing amount of elderly people around the world [12] this issue of memory degradation will effect an ever expanding group of people.

To combat the decline in cognitive functions researchers have developed various ‘brain training’ exercises that stimulate the general mental capacity of the user [5]. These brain training games often involve a kind of interactive exercise with the desired result of these exercises being the increase in certain cognitive functions i.e. processing speed or attention [7].

Developing methods for maintaining and improving cognitive functions in the elderly is therefore a major goal for research into ageing effects.

While the previously mentioned researches have focused on the long term improvement of cognitive functions via these brain training exercises, this research will look into ways of improving the results of the same type of brain training exercises for the short-term memory.

1.1 Related Work
Research from Ericsson et al. [2] has shown that short-term memory can be improved by training via cognitive exercises. Their article describes a study in which a subject was able to increase his short-term memory span from 7 to 79 digits with weekly short-term memory exercises. The participant in this research was read random digits at the rate of one digit per second, and was then asked to repeat the given sequence. If he/she got it right, the sequence would increase by 1 digit. If he got it wrong it would decrease by 1 digit. Ultimately the data from the research suggest that the reliable working capacity of short-term memory is about three or four units, and that it is possible to increase the capacity of short-term memory with practice.

This finding is supported by research from Jaeggi et al. [5] in which it states that:

‘Future research should not investigate whether cognitive training works, but rather should determine what training regiments and what training conditions results in the best transfer effects.’

Memory capacity follows a general power law, which applies both to the number of images retained in memory, and the speed in with which they may be retrieved, according to a study done by Standing [11] on a group of 18-25 year old students. Data from his research shows that pictorial recognition memory follows a power law for capacity and a power law for retrieval time. In his research Standing points out that pictorial memory is quantitatively superior to verbal memory. On average, participants from his study could remember 12 out of 20 images presented in 5 second intervals.

In a later study done by Potter [9], data suggested that when pictures are shown in a rapid rate, they are quickly identified and then usually forgotten unless a further interval of consolidation, free of interruption, is available.
2. PROBLEM STATEMENT AND RESEARCH QUESTIONS

Following the statement from Jaeggi et al. [5] that future work should focus on training regiments and training conditions instead of proving whether cognitive exercises work, this research will focus on enhancing performance of the users by altering the standard exercises. The alteration being a vibrotactile stimulus.

Previous research has shown that tactile stimuli can aid in the recognition of certain sequences, as researched by Mahrer et al. [6] where tactile stimuli was used as a tool to remember numbered sequences with the tactile stimuli being applied to the hand of the participant. A similar research was done years earlier by Gilson et al. [3] who also suggested that tactile stimuli can aid in the retention of short-term memory. Therefore this research is approached from under the assumption that tactile stimuli will be a beneficial aid in cognitive exercises.

However, both researches from Mahrer et al. [6] and Gilson et al. [3] have focused on tactile input via direct touch. Research into the same subject, but with vibrotactile stimuli has not been explored much. With this study, we aim at providing better insights in the retention of STM when provided with vibrotactile stimuli.

This research focuses on answering the following question:

“What effect does the addition of vibrotactile stimuli have on the remembrance rate in a short-term memory cognitive exercise?”

A series of images is shown to a participant. Of these images, half are accompanied by a vibrotactile stimulus. Does the set of images with vibrotactile stimuli have a higher remembrance rate then the set of images without? Does the inclusion of vibrotactile stimuli aid or distract the user in performing their task?

The answer to this research question will help designing and delivering an optimal way to get the maximum potential out of future users in similar tests.

In addition to this central question there are multiple follow-up topics that are interesting to look at. Does age have an effect on the effectiveness of the vibrotactile stimuli? Is there a significant difference in results between male and female users?

3. HYPOTHESIS

This research proposes that when an image is accompanied by a vibrotactile stimulus, a (sub)conscious link will be established between the image and the vibrotactile stimulus. Therefore the images with a vibrotactile stimulus should have a higher remembrance rate than the images without.

Hypothesis: When images are accompanied by vibrotactile stimuli, they will have a higher rate of being remembered than the images without.

4. METHOD OF RESEARCH

4.1 Hardware

During this research, the following hardware was used to perform the experiments: an ASUS N56 Laptop and a wearable vibrotactile device from Elitac [1].

4.1.1 Elitac

The main hardware that was used during this research was a wearable vibrotactile device from Elitac [1]. See Figure 1.

![Figure 1. Elitac Communicator (A) and attached Actuators (B), reprinted from [1](image)](image)

This device consisted of a communicator module (Figure 1 A) which could be connected to a pc via USB. Attached to this communicator were several actuators (Figure 1 B). These actuators could vibrate with different intensities and independently from one another.

The communicator module was programmed to receive signals through a UDP port on the connected pc. Programs could be written to send certain messages to the communicator module, which handled the messages. The signal sent to the communicator module contained the frequency and amplitude, which actuator(s) should vibrate and on a scale of 0-15 how strong the vibration should be. This could be done for each separate actuator or all at once.

An arm sleeve was used to contain the actuators during the experiment. Using the Velcro back to stick them to the arm sleeve, a pattern could be created from the actuators to deliver the desired vibration. For this experiment 6 actuators were used in 2 lines of 3. These actuators were stuck to a sleeve that was fitted around the forearm of the participant. The forearm was chosen because it was the least obtrusive place on the body to place a vibrotactile sleeve that was connected to a computer via a USB cable. The right forearm was used and placed on a cushion on the table next to the computer to reduced sound generated by the vibration on a hard surface.

4.2 Software

A custom Java program was developed to act as an interface for the participants to use during the experiments. The program consisted of the following main features:

- Creating and sustaining a stable connection to the connected Elitac Communicator Module
- Sending Signals to the connected Elitac Communicator Module
- Loading images from a specified directory
- Randomizing the display order of the loaded images
- Randomly assigning 10 images to contain a feedback response
- Logging every action undertaken by the user and the program for analysis
4.3 Images

Since animal photographs can easily be recognized, even at high speeds [4], 20 photographs of animals were chosen out of a set of 400 publicly available photos to be used in this research. The selected photographs contained a wide range of well-known animals. The animals that were selected for this research can be seen in Table 1.

<table>
<thead>
<tr>
<th>Table 1. List of Animals</th>
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<tbody>
<tr>
<td>Chameleon</td>
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<tr>
<td>Gorilla</td>
</tr>
<tr>
<td>(Killer) Whale</td>
</tr>
<tr>
<td>Swan</td>
</tr>
</tbody>
</table>

A sample of the photographs that were used in this research can be seen in Figure 2. (Note, the images shown in Figure 2 are rescaled and gray scaled versions of the actual images used, some detail may have been lost).

Figure 2. Animal Photographs

4.4 Participants

This study has been performed with a total of 17 students from the University of Twente. Due to language and communication problems the test results from one participant were unusable and therefore removed from any analysis in this paper.

Of the remaining 16 students, 11 were male and 5 were female. The students were between 18 and 29 years old with an average age of 22 (SD = 3 years). This group of participants also consisted of multiple nationalities. In this group there were 12 Dutch, 2 Germans, 1 Estonian and 1 Finnish students. None of these students had previous experience with wearable vibrotactile stimuli devices. The students joined the experiment voluntarily and did not receive any compensation for their participation.

4.5 Data Collection

Two different forms of data collection were used during this research. Electronic log-files and comments from the participants after the experiment had finished.

4.5.1 Log files

During the experiment, electronic log files were created by the program for every participant. The data from these log files was used for the final analysis.

The following data could be retrieved from every log file:

- Time and Date of the experiment
- Age of the participant
- Gender of the participant
- Order in which the images were shown
- Which images had vibrotactile stimuli added to them
- Answers entered at the end of the experiment by the participant

4.5.2 Participant Comments

After the participants finished the experiment they were asked if they had any comments regarding their experiences during the experiment. These comments were written down for data collection and evaluation of the experiment.

5. THE EXPERIMENT

Now that the hardware, software, images and participants are established, these combined elements form the experiment. The experiment follows a within-subject design.

5.1 Procedure

The test which the participants are asked to take can be described as having multiple phases. Distinguishing between these phases will help explain the procedure.

5.1.1 Pre-experiment

When the participant arrives at the location of the experiment they are asked to fill in a consent form stating he/she voluntarily participates in the experiment and allows the researcher to make (electronic) recordings for academic use. They are also notified that participation is anonymous.

The participants are told they are about to see photographs of animals with some of them being accompanied by vibrotactile stimuli. They are also told what to expect during phases 3-5 and that the answers could be given in any language he/she preferred and that the order in which they filled in their answers did not matter. They are then asked to take a seat in front of a laptop connected to the Elitac hardware.

5.1.2 Phase 1

The first phase of the program is there to test if the connection to the Elitac Communicator is correctly set and familiarize the participants with the coming elements of the test. With the help of the researcher, a sleeve containing vibrotactile actuators is placed around the forearm of the participant.

After checks are done to ensure a stable and working connection, a trial run is presented to the participants. A total of 3 images are shown, which do not feature in the actual test, with 1 of them having a vibrotactile effect.

The 3 trial images shown are of a great white shark, a herd of antelopes and a humpback whale, as shown in Figure 3.

Figure 3. Trial Images

These images were specifically chosen because they are ambiguous. On the basis of these images the participants are told that they should focus on the main animal shown on screen, and not to worry about the specific species of animal it is. Instead of 'great white shark' and 'humpback whale', both 'shark' and 'whale' would also be accepted. They participants are also told not to worry about spelling mistakes.
5.1.3 Phase 2
In the second phase of the program the participant is asked to type in their age and select their gender. After this is done a start button has to be pressed to start the actual experiment. When the participant is ready to start the researcher wishes him/her the best of luck and retreats out of sight of the participant.

5.1.4 Phase 3
The third phase is the main part of the test. In this phase 20 images are shown in 3 second intervals. The images are shown in a random order. From these images 10 are selected at random to have a vibration effect. A vibration intensity of 5 out of a possible 16 was used for this experiment with a 2 second duration for all the actuators. The tactile stimuli started directly when the image was first presented to the participant, and ended 1 second before the next image was shown. This was done to avoid creating a continuous vibrotactile stimuli if the images happened to be sub sequential.

5.1.5 Phase 4
The fourth phase starts automatically when all of the images from the previous phase have been shown. In this phase a text will appear on screen which asks the participant to carefully remove the sleeve and get ready to input the answers. This phase lasts 10 seconds.

5.1.6 Phase 5
In the final phase of the experiment the participant is able to input as much as they can remember from the third phase. There is a 60 second countdown timer on screen to signal when the experiment is about to end. When the timer reaches 0 seconds all information from the test is stored and logged in a log file and the participant is asked to alert the researcher that he or she is done with the experiment.

5.1.7 Post-experiment
When signaled by the participant that he/she is done with the experiment the researcher will thank them for their cooperation in the experiment and ask them if they had any comments regarding their experience. After all comments have been written down the participant is asked not to reveal details of the experiment to others.

6. RESULTS
Looking at the results of the experiment, we distinguish 3 different types of correct answers. Feedback Correct Answers (FCA), which are defined as the number of images answered correctly that were accompanied by vibrotactile stimuli. NonFeedback Correct Answers (NFCA), which are the number of images answered correctly that did not have a vibrotactile stimulus added to them. And Total Correct Answers (TCA), the total amount of correct answers given by the participant, which is the sum of the FCA and NFCA.

6.1 Feedback Correct Answers
From the 20 images shown to the participants, 10 had vibrotactile stimuli added to them, which is the maximum amount of FCA possible. With 16 total entries, FCA scores had a minimum of 2 and a maximum of 9. With a mean score of 5.50 (SD = 1.97). The individual scores of the participants are shown in Figure 4 with a line representing the mean score.

6.2 NonFeedback Correct Answers
From the 20 images shown to the participants, 10 did not have tactile stimuli added to them, which is the maximum amount of NFCA possible. With 16 total entries, NFCA scores had a minimum of 2 and a maximum of 8. With a mean score of 4.63 (SD = 1.54). The individual scores of the participants are shown in Figure 5, with a line representing the mean score.

6.3 Total Correct Answers
Combining both the FCA and NFCA we get the TCA score of the participants. With a maximum amount of 20 and 16 total entries, the minimum TCA score was 8 and the maximum 13. With a mean score of 10.13 (SD = 1.78). The individual scores of the participants are shown in Figure 6 with a line representing the mean score.
When comparing the graphs of the FCA, NFCA and TCA scores the first thing to note is the variation in results between the FCA/NFCA and the TCA scores. While the results from the TCA stay relatively close to 10, there is a much greater variation in scores, especially the FCA scores of the participants.

Even though the FCA scores have a wide variation in results (SD=1.97) compared to the NFCA scores (SD=1.54), the mean score of the FCA results are higher than the NFCA scores. With the FCA having a mean of 5.50 against a mean score of 4.63 of the NFCA result. This is a 0.87 increase in points, or about 9% increase in results. By overlapping the graphs from the FCA and NFCA scores we get a clearer picture of the situation.

As shown in Figure 7 with the FCA scores in black and the NFCA scores in gray, we can see that in only 5 out of 16 cases the number of NFCA is higher than the FCA. The results also show a high negative correlation between the NFCA and FCA results, r = -0.50. Comparing the data as shown in Figure 7 with the comments from the participants, we can see that the 2 participants (p4 & p10) who explicitly stated that they felt the vibrotactile device was a distraction rather than an aid, are included in the 5 results where the NFCA score is higher than the FCA score.

Further analysis of the data via a paired sample t-test showed no significant differences between the FCA and NFCA scores (t(15)=1.15, p=0.27). This would suggest that, while there is a trend in the data, we cannot conclude that vibrotactile stimuli had a positive effect on the results.

However, if we omit the data from the 2 participants who stated that they felt the vibrotactile feedback was a distraction, and perform a paired sample t-test, data shows that there would be a significant difference between the FCA and NFCA scores (t(13)=2.26, p=0.02).

### 6.5 Animal Scores

Every participant in this study was shown 20 images of animals, see section 4.3 of this paper. With a maximum score possible of 16 per animal, results show that the kangaroo was remembered the least amount of times with a score of 2, and that the most remembered animal was the lion with 13 correct answers. A mean score of 8.10 (SD = 3.18) was measured across all of the 20 animals. The individual scores of each animal are show in Figure 8 with a line representing the mean score.

Looking at the differences between male and female answers we can see that the mean female score of 6.05 (SD = 3.63) is slightly higher than the mean male score of 5.35 (SD = 1.95). With the top 3 scoring animals for each respective gender being; lion, giraffe and tiger for the male participants, killer whale, elephant and polar bear for the female participants.

### 6.6 Order

Every participant was shown 20 images, of which the order was randomized for every experiment. By looking at the results for each individual participant and combining them into a total figure, we can see the results for the first, second, third until the twentieth image shown in order.

With a maximum score possible of 16, results show that the 2nd image shown to the participants, was remembered the most with 15 correct answers. With the 25th image being the least remembered with 3 total correct answers. A mean score of 8.10 (SD = 2.71) was measured across all of the images. The scores for every image in order of appearance is shown in Figure 9 with a line representing the mean score.
A similar statement can be made about the age distribution in this research. Because all of the participants in this research were students at the University the age range is naturally between 18 and 28 years old. It could be interesting to know if the same results of this study apply to people in different age ranges.

Even though there were participants from 5 different nationalities, the social difference amongst the participants was minimal. All of the participants were students at the University of Twente in the same age range with most of them having similar interests tending to computer sciences and human psychology. A follow-up study should include participants from a more diverse group of social differences to confirm that the findings from this research are still valid, or differ, for a higher social diversity.

Despite the program being in English and the instructions being given in either English or Dutch, depending on the nationality of the participant, there were still issues regarding foreign nationalities. Even though the instructions made it clear that participants could type in their native language, some of them still typed in English answers because the on-screen instructions were in English. In the case of one participant the keyboard layout used in this research differed from the one they were accustomed to. This meant some characters on the keyboard were in different positions than the ones they were used to. These problems could have had some influence in the final results since there is a 60 second time window in which the participant has to type in his/her answers.

For this research a single cognitive exercise was used to test the hypothesis and research questions. Due to the time constraints of this study developing and testing multiple exercises was not possible. However, to avoid exercise specific conclusions the findings from this study should be tested across multiple cognitive exercises to solidify the results. An example of which would be to present the same exercise as mentioned in this study to a larger group, of which half would not get any vibrotactile stimuli and the other half did. This would give more prove whether vibrotactile stimuli effected the overall score.

The last items to mention in this discussion are the images itself and the order of the images during the test. Since previous research had shown that animal images were easily identifiable [4], even at high speeds, they were chosen for this experiment. Sorting through the set of 400 publicly available animal photographs, a selection of images were chosen on the basis of visual clarity and the notoriety of the animal in the photograph.

Looking at the animal scores in section 6.5 we can see that some of the animals were remembered much less than the mean amount of 8.10. With the bottom 3 being; kangaroo (2), hare (3) and chameleon & swan (4). A definitive reason as to why these images are remembered so much less than the mean cannot be given. A case could be made that these 4 animals are less grandiose than a lion or a tiger, and therefore less likely to stay in memory, but that would not explain why animals like the turtle, owl and penguin scored above average.

When looking at the order of the images a surprising statistic can be deconstructed from the data. From the 16 participants of the experiment, 10 (62.5%) remembered the first image in the sequence while only 7 (43.75%) remembered the last image in the sequence. Since only 10 seconds separates the final image from the final phase, see section 5.1.6, in which the participant gets to input his answers, that image should be fresh in his/her mind.

7. DISCUSSION

The results show that there is a slight increase of around 9% in the recollection rate of images assisted with vibrotactile stimuli. However, upon further examination of the data, no significant difference was found between the images without and the images with vibrotactile stimuli. The hypothesis therefore, cannot be proven by the results from this study. It should be noted however, that the hypothesis would be confirmed if the 2 participants that felt they were distracted by the vibrotactile stimuli were omitted from the results.

The large variation in the FCA results could be explained by the various comments of the participants after the experiment was over. Most of the participants commented that the vibrotactile stimuli was an asset in recollecting the different images. Some of the participants however felt that the vibrotactile stimuli was a distraction in remembering the images. This is reflected in the low scores for some participants in the FCA results. It remains unclear why there is this separation of feeling towards the assistance of vibrotactile stimuli.

When comparing the mean result from the TCA to the same type of study done by Standing [11], in which he also presented participant with a set of 20 images, we can see that the mean score of this research is lower (10.13) compared to the result of Standing’s research (12). The difference between these 2 numbers could be explained by the fact that Standing used 5 second intervals for his research whereas this research used 3 second intervals. Standing also used a larger range of photos which included animals as well as other subjects.

The number of people that participated in this study is too low to make an accurate statement about the final conclusions from this study when discussing future research. However, as pointed out in section 6.4, the overall result was profoundly affected by the 2 participants who felt that the vibrotactile stimuli was a distraction which reflected in their scores. It would be interesting to know if a similar research done on a larger scale would result in a significant difference between NFCA and FCA scores.

The gender distribution was not big enough in this study to make accurate statements about male vs female performance when looking at and analyzing the results of FCA, NFCA and TCA scores.
Possible explanations for the overall curve of the graph in Figure 9 are the primacy- and recency effects [8]. The primacy effect suggests that initial items are most effectively stored in long term memory because of the greater amount of processing devoted to them. This effect is reduced when items are presented at a faster rate. The recency effect suggest that the last seen items are still present in working memory. Looking at both effects show that items presented in the middle of the sequence benefit from neither the primacy- nor the recency effect. This could explain why the 9th image is remembered so poorly.

Further looking at the individual data from each participant we can see that the most frequent images shown as 9th in order were the swan (4), the chameleon (2) and the kangaroo (2). Looking at Figure 8 we can see that these 3 animals are in the bottom 4 of most remembered animals. As explained by the primacy- and recency effect, a case could be made that being shown 9th effected the scores of these animals. However, this is just speculation.

8. CONCLUSION
This research was conducted to see what effect the inclusion of vibrotactile stimuli has on the results of a short-term memory cognitive exercise. With the premise being that the elements of the experiment which included vibrotactile stimuli would score higher than the elements without. Data shows that there is a trend between vibrotactile stimuli and its effect on performance. A small overall increase in participant performance was measured when presented with vibrotactile stimuli. However, the difference measured between the images with and without vibrotactile stimuli is not statistically significant.

It should be noted however that while the majority of the participants felt they benefited from the inclusion of vibrotactile stimuli, a few experienced the vibrotactile stimuli as a distraction rather than an aid. This is reflected in the overall results. If the scores from these participants are omitted from the analysis, a statistically significant difference can be seen between the images with, and the images without vibrotactile stimuli.

While vibrotactile stimuli seems to have a positive influence on the majority of student scores in this exercise, whether this result also applies to a different subset of people remains to be seen. However, the results from this study show a positive prospect for future research.

If future research confirms that vibrotactile stimuli has a positive influence on participant results, real-life applications like brain-training games could be outfitted with a vibrotactile component to further improve the results and benefits from those kind of short-term memory exercises. With the ultimate goal being the further improvement of cognitive functions and general mental capacity of the users.

9. REFERENCES