The influence of uni- and bimodal stimuli on the working memory performance in a 3-back task

Bachelorarbeit der Mathematisch-Naturwissenschaftlichen Fakultät der Eberhard Karls Universität Tübingen

vorgelegt von

Annika Utz

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Erklärung

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Tübingen, den 22. Oktober 2014

Zusammenfassung

Es ist bekannt, dass beispielsweise Vokabeln leichter einzuprägen sind, wenn diese sowohl visuell als auch auditiv präsentiert und verarbeitet werden. Durch wissenschaftliche Studien konnte bereits ein Vorteil für das Memorisieren von bimodal präsentierten Stimuli nachgewiesen werden. Um einen möglichen Vorteil der Präsentation und Verarbeitung bimodaler Reize bezüglich der Prozesse im Arbeitsgedächtnis zu untersuchen, wurden die hier vorgestellten n-back Experimente durchgeführt. Die Versuchspersonen wurden dabei in drei Gruppen eingeteilt. Jede Gruppe musste einen 3-back Task unter verschiedenen Bedingungen bearbeiten. Der Gruppe 1 wurden rein visuelle Stimuli, der Gruppe 2 rein auditive präsentiert. Der Gruppe 3 hingegen wurden bimodale, audiovisuelle Stimuli präsentiert. Für die Analyse und Quantifizierung der Arbeitsgedächtnisleistung wurden mit Hilfe der Signaldetektionstheorie die d-prime Werte für jede Gruppe ermittelt. Gegenüber dem unimodalen Lernen konnte für bimodales Lernen hierbei kein Vorteil identifiziert werden. Dafür gab es über die einzelnen Experimentblöcke in der visuellen Gruppe einen starken und in der bimodalen Gruppe einen mittleren Lerneffekt. Für die auditive Gruppe konnte kein Lernen über die 5 Experimentblöcke hinweg festgestellt werden. Obwohl andere Studien darauf hinweisen, dass multimodale Verarbeitung von Reizen im Arbeitsgedächtnis bessere Repräsentationen und somit Leistungen bedingen, konnte dieser Effekt mit der aktuellen Studie nicht nachgewiesen werden.

1 Introduction

The principle idea of a bimodal (cross-modal) advantage of stimuli presentation and processing is already and commonly used in education, particularly in language learning programs. The times of learning vocabulary lists tediously out of a book may be over. Nowadays language course books include CDs and vocabularies are colorful depicted. For this bimodal advantage, scientific support can be found as well. The following study was conducted to analyze such an advantage of bimodal stimulation on memory performance.

1.1 Models of Working Memory

There are several defined structures of the human memory system. The long-term memory is generally defined as a storage of knowledge and records prior events. It appears in almost every theoretical model. The short-term memory on the other hand is related to the primary memory of James (1890) who divided the memory into the primary memory, which holds just little information and the secondary memory, which stores the gained knowledge of a human and is not as widely accepted as the long-term memory. Also the definition is controversial. A definition of Atkinson and Shiffrin is that it holds a limited amount of information in an accessible state for a limited time (Atkinson & Shiffrin, 1968). The working memory is very hard to distinct from the short-term memory. Miller defined it as a memory which is used to plan and carry out behavior. Several studies also found out that it is a good measuring method for intellectual competence (Cowan, 2008).

At the moment, there are two major theories about working memory: the Multicomponent Model of Baddeley & Hitch (1974; Baddeley, 2002) and the Embedded Processing Model of Cowan (1988).

1.1.1 The Multicomponent System of Baddeley

According to Baddeley (1974) the working memory consists of three different subsystems. These are two slave systems which are controlled by the central executive. One of the slave systems is the visuospatial sketch pad which is important to process visual stimuli. The other one is the phonological loop, a store for speech-based information and important for language learning.

A study which supports the hypothesis of a central executive was performed by Baddeley in 1986. All subjects had to perform first a visual and a verbal task separately. Performance of Alzheimer’s patients, healthy participants in the same age and young adults was measured. The difficulty level at which the participant performed the task error-free was used to design the dual task. This ensured that a comparison of each participant could take place. Performing the dual task with their own level of difficulty, the Alzheimer patients showed major impairments compared to the other two groups. The explanation for this was that the central executive is affected in Alzheimer patients. The performances of Alzheimer patients and healthy participants in the same age were quite comparable when looking at the visual task and the verbal task performed separately. However, when the central executive was impaired the control system cannot coordinate the two slave systems properly and the performance decreased (Baddeley et al., 1986). Baddeley concluded from this and many other experiments that the central executive is important for the storage of information, decision making and the attentional focus. All these functions make the central executive a very powerful structure and thus difficult to investigate it.

The phonological loop has many functions concerning the processing of speech. It is essential for the understanding of complex sentences. It is also assumed that it plays a role in long-term phonological learning. Baddeley (1992) carried out a study with a patient who suffered from a short-term phonological memory deficit. His task was to learn words of a language he was not familiar with (Russian) and to associate arbitrary word pairs in his native language. He had no problems with associating the word pairs but he could not learn the Russian words auditory. His performance was also impaired when he saw the written words. As explanation the authors claimed that native word pairs are learned by the meaning of the words, while the Russian words could only be learned by their phonology code as they do not have a meaning for the patients. As he only has a short-term phonological memory deficit it can be assumed that this memory is also necessary for new long-term phonological learning (Baddeley, 1992). Some other effects were found which can be explained by the phonological loop easily. One is the phonological similarity effect. Here, it appears that it is easier to recall dissimilar sounds than similar ones (Baddeley, 1992). This finding is interpreted as an indication for phonological storage (Baddeley, 2007) or even a basic phonological code. Similar items have fewer distinguishing cues and are therefor forgotten more likely. This similarity effect does not occur when words are similar in their meaning which implies that there is no semantic coding.

The visuospatial sketch pad on the other hand is important for visual stimuli. Visuospatial information is maintained temporally and manipulated as the sketch pad serves as an interface between spatial and visual information. Information of the visuospatial sketch pad is provided by our senses or the long-term memory. The sketch pad is essential for orientation as well (Baddeley, 2002). To distinct the spatial and the visual part of this slave system, specific tasks have to be tested. Measuring the spatial span can be achieved with the Corsi task (Corsi, 1972). Here, an array of nine blocks is placed in front of the participant. The experimenter starts with tapping on only two of those blocks and the participant has to repeat this sequence in the right order. The sequence length increases till the performance breaks down. To measure the visual pattern-span participants have to look at a matrix of cells of which 50% are randomly filled. Then the matrix is removed and the participant has to choose which cells were filled. The size of the matrix is at first 2x2 and increases during the experiment till the performance breaks down. While measuring the spatial span with the Corsi task, the performance was more disrupted by concurrent spatial processing than visual interference. For measuring the visual pattern span the opposite occurred. This would be an argument for a distinction between visual and spatial processing. Researchers also discuss if the visuospatial sketch pad is divided into static and dynamic coding. How exactly the parts of the sketch pad are characterized is not clear yet and requires further study (Baddeley, 2007).

Another part of the model, called episodic buffer, was added by Baddeley 26 years after the multicomponent model of the working memory was published (Baddeley, 2000). This was due to some deficits of the former model. In the old model the central executive served as a limited capacity controller and as storage. This made the central executive very powerful and difficult to investigate (Baddeley, 2002). A study of Baddeley et al. (1987) showed that participants could recall about 5 unrelated words but up to 16 words when they were presented within a sentence. Patients which had a short-term memory deficit but a functioning long-term memory could only recall 5 words although they should have recalled about 11 (Baddeley et al., 1987). This indicated that the long-term memory was not responsible for these 11 other words as Baddeley first assumed. In order to explain this outcome the episodic buffer was added to his model (Baddeley, 2002). The episodic buffer is thought of as a temporary multidimensional store and serves as an interface between the subsystems of the working memory, long-term memory, and the central executive. The integration involves sources of information to form chunks. The episodic buffer is a storage system with a limited chunk capacity of about 4 items. It is accessible through consciousness and provides a multi-feature binding mechanism. (Baddeley et al., 2011).

1.1.2 The Embedded-Processes Model of Cowan

Cowan's Embedded-Processes model (Cowan, 1999) does not divide the types of memories as sharply as Baddeley. He assumed that the short-term memory derives from a temporally activated subset of representation in the long-term memory. These activated subsets decay as a function of time unless it is refreshed and the subset of activated information is in the focus of attention. The memory span is limited in chunk capacity which is the number of separate items included at once (Cowan, 2008).

Cowan divided the sensory storage into two phases. The first phase is the initial phase which lasts a few hundred milliseconds and is represented as the brief sensory store (Cowan, 1988). Plomp (1964) conducted a study in which he measured how much time had to pass between two noisy pulses to perceive them as two pulses. The inter-stimulus interval was measured at about 200-300 milliseconds (Plomp, 1964). Such a task is accomplished by the brief sensory store that holds modality-specific and continuous information for a very short time.

The short-term store on the other hand maintained information for about 20 seconds (Cowan, 1988). In a study (Postman & Phillips, 1965) participants had to recall a list of words after a specific duration of counting. While the counting duration increased up to 30 seconds the recency effect (stimuli presented at the end of a presentation can be more easily recalled than stimuli presented earlier) decreased. The short-term storage consists of activated information of the long-term memory. In this activated long-term memory our focus of attention is embedded. The focus of attention is just a fraction of the perceived information and represents information which is aware to us (Cowan, 1988). There are some studies which show the distinction of different modalities. One study concerning distinctive memory stores of the visual modality is the one from Posner et al. (1969). Participants had to compare name and physical form of a visually presented letter (for example: ‘A’ and ‘a’ have the same name but different physical forms) There was an interval from 0 to 2 seconds between the letters. When the same physical forms were presented the performance was better if only a short interval separated them. When the interval increased the performance got worse (Posner et al. 1969).

Unlike in Baddeley’s model, the central executive of Cowan is under conscious control. It processes information with a limited pool of processing capacity. Cowan characterized five operations which fall under the processing control of the central executive. First, the central executive selects information from the short-term memory. It also scans the short-term memory and selects items from incoming stimuli or the long-term memory. Further operations are rehearsal to maintain information in the short-term memory and long-term memory searches which lead to a transfer of short-term memory items to the long-term memory. The final operation concerns problem solving activities, for example the recombination of short-term memory items to form new associations (Cowan, 1988).

Chunks are unlinked bits of information which are stored and recalled as one piece. Miller (1956) assumed that the limit of the chunk capacity would be seven as this was the memory span assessed for adults. Cowan limited the chunk capacity to three to four items, because it was not clear if any of these seven items are integrated to a bigger chunk. He and others carried out many studies which supported this assumption. However, this involved some problems. There was the chunking itself. Chunks could be of any size so it is very problematic to figure out the true number of chunks. But there were some observations which support the capacity limit of three. A list of three items is recalled error-free while a list of seven is not. Another observation was that if participants recalled items from a category stored in the long-term memory, they pause after three items repeatedly. In addition the capacity limits differ strongly in adults and children as it is correlated with the cognitive capacity of the participant.

Another problem is about rehearsal. Baddeley claimed that the items which could be rehearsed sub-vocally within two seconds represented the capacity limit for the short-term memory. Cowan on the other hand assumed that rehearsal affects the performance of the participants but is not a prominent criteria. When Cowan interviewed participants after the digit span experiment, almost all reported that they grouped the items together but did not rehearse them. He assumed that they used rehearsal only to put the items into groups. To prevent rehearsal at all, Cowan presented four items per second to make rehearsal temporally impossible. Another approach is to present a list during the experiment which should be ignored while paying attention to something else. After this presentation the participant had to recall as many words as possible from the list. Here the capacity limit is also about four items. (Cowan, 2008)

1.2 Cross-Modal Perception and Processing

Cross-Modal processing has a great impact on the perception of our environment. It combines for example the visual picture of a car and its sound to form one experience. For this processing special cells are necessary.

1.2.1 Sensory Perception of Cross-Modal Input

Environmental information input is provided by our senses. The more senses available the more detailed is our presentation of the environment and the earlier cues are detected at all. This process is even fastened by multisensory integration. Multisensory integration combines cross-modal stimuli, for example visual and auditory cues, to an audiovisual cue. Single multisensory neurons are responsible for this integration.

Each modality which gives input has its own qualia, which is the subjective impression a sensation provides to the recipient. Thus, for a different event there is a different modality which can detect and describe the situation the best and quickest. Just integrating input from all modalities is not sufficient. These modalities have to be weighted according to the importance of the given information for this event. These processes are normally not conscious but some illusions show that the environment is not represented properly by our brain (Stein & Stanford, 2008).

One of the most famous cross-modal illusions is the McGurk effect (McGurk & MacDonald, 1976). This effect is based on our habit to read the lips of a person talking to us improving the identification of speech significantly. This is very important in situations where we are surrounded by a very loud environment. Only silent articulation alone can change the activity of the auditory cortex just as normal loud articulation. What a person says normally fits together with its/his lip movements. However, when the movement of the lips and the articulation are not concordant the brain creates a mixture of these two contrary information (Sato & Troille. 2013).This effect is present in most adults but less profound in children. Even if the test persons know about the mechanism of this illusion they are still influenced by it (Sams & Aulanko, 1991).

Another consequence of cross-modal perception outcome is the famous Ventriloquism effect (Alais & Burr, 2004). It also affects auditory and visual stimuli which coincide in time but not in space. This leads to perceptional translocation of the sound towards the region of visual input. The explanation therefor is that vision usually dominates over auditory input as it has a higher spatial reliability (Magosso & Cuppini, 2012).

1.2.2 Cellular Processing of Cross-Modal Stimuli

The multisensory neurons can be found almost everywhere in the brain. A large amount of these cells were identified in the cerebral cortex and especially in the superior colliculus (SC) of cats which is why so many studies aiming to understand multisensory integration concern this structure. The SC controls changes of orientation and gets input from ascending sensory pathways (visual, auditory, somatosensory) as well as from descending projections from the cortex (Stein & Stanford, 2008).

The SC is part of the midbrain and transforms sensory cues into a motor response. In 1986 Meredith and Stein carried out a study concerning multisensory integration within the SC of cats (Meredith & Stein, 1986a). They measured the output of single multisensory neurons while either providing a cue from only one modality or giving cues from two different modalities. Based on their results they drew several conclusions. First, they concluded that a combined-modality stimulus located in the receptive field leads to a response enhancement. The enhancement is generally multiplicative and not summative. Second, they measured the highest response when the two stimuli coincide in space and in their receptive fields. This was best observed in cells which received auditory and visual input. Another observation was that if one stimulus was outside of the receptive field no enhancement or even a depression of the response of this specific neuron was found (Meredith & Stein, 1986a). In a later study Meredith and Stein also found out that if an enhancement of the response occurs it will be greater the weaker the responses of the single stimuli are (Meredith & Stein, 1986b).

Spatial and Temporal Processing. Each multisensory neuron has a receptive field for each modality it receives input from. These receptive fields have similar regions of sensory space. As mentioned before, two stimuli which coincide in space and in their receptive fields will be integrated and lead to a response enhancement that exceeds the individual modality response beyond even their sum. This effect has not been observed within the same modality. Stimuli which are not caused by the same event are unlikely to be at the same location and therefor fall outside the border of the receptive field. This leads to a depression of the multisensory response. A study performed by Wallace & Stein (2001) showed a high degree of spatial correspondence between visual and auditory receptive fields although this degree of overlap could vary highly. There was no relationship between the spatial disparity of auditory and visual stimuli and the magnitude of multisensory interaction. In general, a maximal response was found when the receptive fields were overlapping (Kadunce et al., 2001).

Besides this spatial importance for multisensory integration there exists also a temporal relevance. Meredith & Nemitz (1987) showed that there are maximal levels of response enhancement when the peaks of two different modality inputs overlap. The more temporally disparate two stimuli were the more decreased the magnitude of this enhancement monotonically to zero (Meredith et al., 1987).

Processing in Humans. Many of the studies mentioned above have been conducted with cats. Studies of multisensory integration in humans concentrated mainly on the posterior parietal cortex (PPC) where sensory input from visual, vestibular, tactile, and auditory systems converges. This structure is relevant for spatial awareness and the guidance of action towards spatial goals. It also transforms sensory signals into a coordinate frame which helps to guide the gaze or reaching behavior. These multisensory neurons also have to deal with the shifting of receptive fields after every eye or body movement. The referring frame has to be re-mapped after such a movement. Studies have however documented that these fields just shift partially, especially in cortical areas. An assumption is that these neurons may help to enable efficient transforming between two coordinate forms (Stein & Stanford, 2008).

1.3 Influence of Cross-Modal Stimuli on Working Memory

Research which concerns the working memory deals not only with the structure of it but also with the function. It is important to analyze how our working memory works and how we can improve its functionality. As mentioned before, our perception depends on the input of our senses. Input from different senses can be combined to fasten recognition and thus reaction. The question is how big the influence of these cross-modal stimuli on our working memory is and if there exists such an influence at all. There are different opinions about whether the modality or the content of a stimuli are important for an improvement of working memory.

The Influence of Modality and Content. A study which dealt with both content and format of a stimulus was the one from Goolkasian & Foos (2005). Participants had to recall a number of items. These were presented either unimodal (as picture, printed word, or spoken word) or bimodal (as picture and printed word, picture and spoken word, or printed word and spoken word). While doing this, they had to verify mathematical sentences with various levels of difficulty. First of all, the authors found an advantage for all bimodal formats, and the best recall performance when the presentation was audiovisual. When the difficulty of the mathematical sentences increased, the recall performance of items presented as pictures and printed words decreased but not for printed word. Goolkasian & Foos (2005) assumed that written words would require fewer processing resources than spoken words and pictures. This study showed that there is an improvement for bimodal presentation compared to the unimodal one.

Another aim was to analyze the content or the modality of the stimulus on its own, avoiding as much influences as possible. De Gelder & Vroomen (1997) carried out a study concerning the content of the presented items in recall. They used four different formats of stimulus presentation: written and spoken (speech items) as well as environmental sounds and drawings (non-speech items). They found an advantage for spoken words shown at the end of the presentation but no advantage for printed words and drawings shown at the end. Environmental sounds on the other hand were found between spoken words and printed words and drawings in recall performance. The authors concluded that spoken words have two features: an auditory base code and a speech based code. Thus, spoken words, which have an auditory base code and a speech based code are recalled best (De Gelder & Vroomen, 1997).

The Modality Effect and Dual-Code Theory. The traditional view has always been that following perception, our brain extracts the meaning of these perceived stimuli which defines the basis of the memory. In 1984, Paul Kolers suggested a different kind of view. He assumed that knowledge and its representation is dependent on how this knowledge was obtained. This is the proceduralistic view: the perceptual processing is the basis of the memory trace and the meaning is added later. The later view is based on the importance of the modality. The modality effect is an example of the influence of the modality. It describes the phenomenon that auditory presentation results in a higher recall rate than visual one (Penney, 1989). Many studies found an advantage in recall performance if items were presented within two modalities. Here, instead of just presenting it visually the items were presented audiovisual. Thompson & Paivio (1994) conducted a study in which participants had to memorize environmental items. They were presented in different ways: visually as a picture, auditory as a sound, and in combination. The dual modality condition showed additive recall performance compared to single modality conditions. The authors concluded that auditory and visual components of audiovisual items are functionally independent in memory (Thompson & Paivio, 1994). An attempt to explain these findings was the dual-code theory of Paivio (1988). This theory describes an item as a composition of different modalities which are stored and processed independently. According to Paivio, there are two basic codes: a non-verbal imaginary and a verbal one. Hence, if a bimodal and nameable item was presented, its visual appearance was processed by the non-verbal subsystem while the name of the item was maintained in the verbal subsystem. Here, the item was double encoded and thus easier to recall (Paivio, 1988).

Mastroberardino (2008) discussed in an overview how bimodal presentation influences the working memory. He concludes that a bimodal advantage exists in working memory tasks but not in cognitive tasks like problem solving. This advantage of bimodal presentation is more effective when a recall task has to be accomplished. He linked these findings with the necessity to improve e-learning programs which can be described as education with the help of electronic media (Mastroberardino, 2008).

Diehl (2013) conducted her bachelor thesis with an aim to analyze this bimodal advantage using very abstract and completely unfamiliar stimuli. The participants of her study had to perform a 2-back task and were divided into three groups. For each group stimuli in a different modality were presented. The stimuli were either presented visual, auditive or audiovisual. Her findings supported a bimodal advantage but not on a highly significant level as the participants could pass the task too easily (Diehl, 2013).

To identify a greater effect with a higher significance and thus a more conclusive result, now a 3-back task was conducted in this study. This will increase the difficulty level and hopefully the clearness of a bimodal advantage. Thus, the hypothesis is that a bimodal presentation of stimuli improves the working memory performance of participants compared to a unimodal presentation of stimuli.

2 Material and Methods

2.1 Participants

The experiment was conducted with 36 students between 20 and 27 of the Eberhard-Karls University Tübingen. The participants had to be naive with the experiment design to prevent influence based on learning effects. They were divided into 3 groups of 12 people. Each group had a different condition which means different kinds of stimuli were presented to the participants.

2.2 Apparatus

A psychophysical experiment was conducted with an n-back working memory task. Each participant performed the n-back task in front of a monitor dealing with visual and auditive stimuli. For this experiment a 3-back task was conducted with the help of Matlab R2013 b and Psychtoolbox. The program was provided by Dr. Gregor Hardiess. The resolution of the 19 inch-monitor was 1280x1024 and the distance of the monitor to the participants was about 52 cm.

2.3 Procedure

N-back tasks are used among other things to measure working memory ability. When performing a n-back task a participant has to tell whether the presented stimulus is the same as another stimulus shown a few places beforehand. Depending on which kind of n-back task (1-back task, 2-back task ...etc.) is performed the participant has to compare the shown stimuli with the one shown one place, two places...etc. before (Kirchner. 1958). For this experiment a 3-back task was conducted. At the beginning a short summary of the instruction was shown on the monitor. The sequence could be started with any key by the participant. Before the sequence started, a fixation cross was shown to get the participant focused. Each stimulus was presented for 2 seconds and followed by a grey screen which lasted 1 second (s. fig. 2.1). During these three seconds the participants were instructed to press either the left mouse button to identify the stimulus as the one shown three positions before or the right mouse button to affirm that it is not the same stimuli. Besides the responsiveness the reaction time was also measured. The next stimulus was presented after these 3 seconds whether a button was pressed or not. There was also no feedback given. Between every block of 60 stimuli a text was shown on black screen to show the progress. The next block started after pressing a button on the keyboard. So after every block the participant could make a break as long as they wanted. After the fifth block a text was shown to inform the participant that the experiment can be ended with pressing a key again. The results were saved as a text document. The experiment took altogether about 15 minutes.

For every condition the same pseudo randomized pattern of signal distribution was used (s. A.1). In every block a different number of signals was used (block 1: 21 signals, 2: 16 signals, 3:21 signals, 4: 24 signals, 5:18 signals) and the sum of all hits in total is 100.

The experiment was followed by a questionnaire to find out about motivation, self-assessment and how difficult they found the task (s. A. 2).

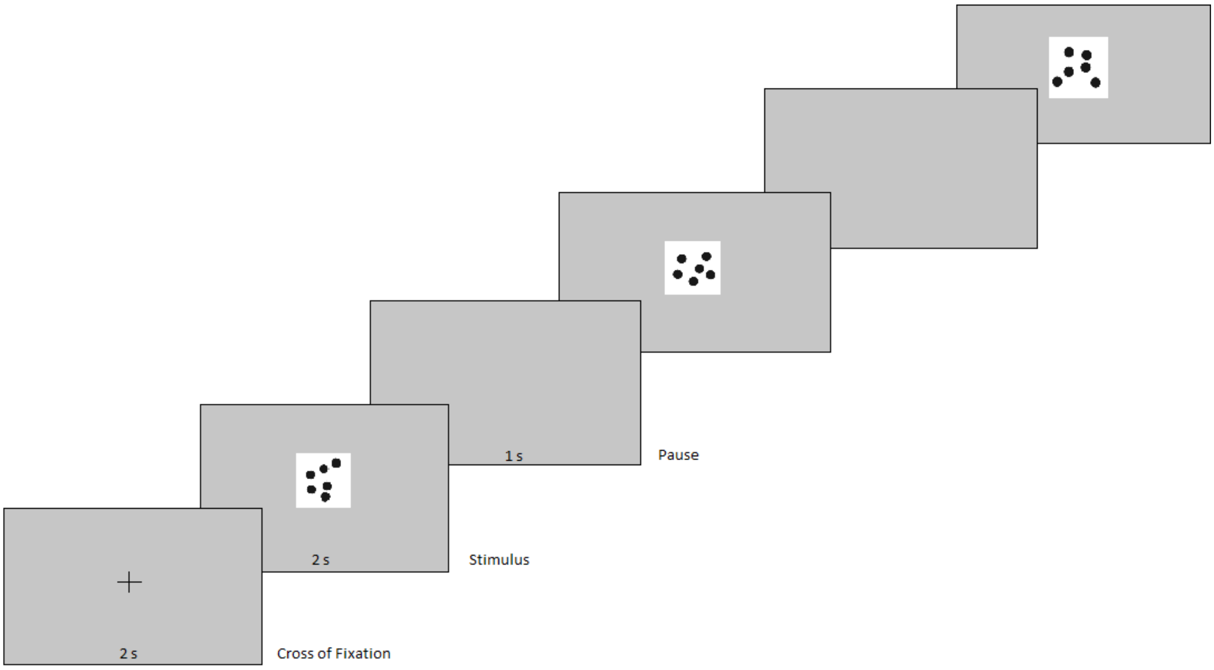

Fig. 2.1: Beginning sequence of the experiment within the visual group.

2.4 Stimuli

As said before the 36 participants were divided into three groups and for each group a different instruction (s. A. 3) was given. The first group had to perform a visual n-back task. After reading the instruction and asking open questions the participant sat down in front of the monitor. 6 different pictures were shown in a specific randomly organized sequence of 60 stimuli. In each block a different variety of 6 pictures were shown. Altogether there existed 12 pictures to choose from (s. fig. 2.2). Those pictures were drawn manually with CorelDraw and presented on a grey screen (width and length of picture: 6.2 degree). Each picture showed a white square with 6 dots. Those dots were randomly organized to prevent an association with known objects and thus a verbalization. Nevertheless they still have to be distinguishable from each other.

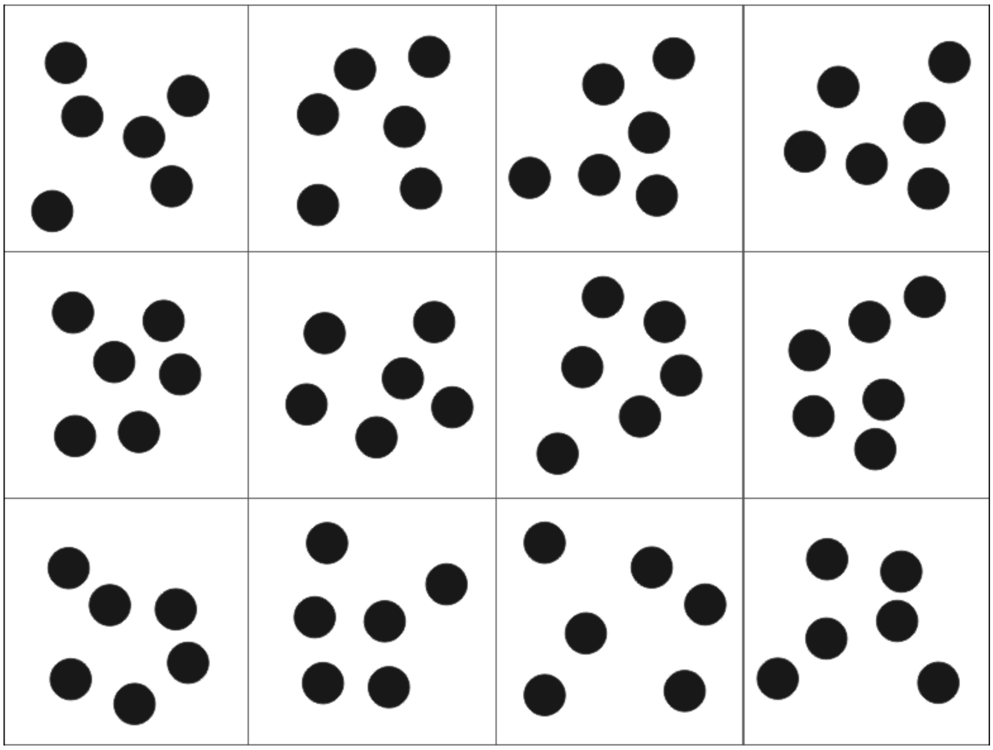

Fig. 2.2: Visual stimuli of the 3-back task.

The second group dealt with auditive stimuli. Those were presented via stereo headphones in a comfortable volume. Those 6 auditive stimuli were sinus tones of the pentatonic. The tones are c, d, e, g and a. The normal c has a frequency of 262 Hz but was put to 300 Hz to prevent a verbalization by very musical participants. This tone was multiplied with $\sqrt[12]{2}$ to create a new scale. (Frequencies: 300, 337, 378, 450, 504.5, 600 Hz). This pentatonic characteristic has the advantage that no semitones occur and thereby facilitate the distinction of the stimuli. To prevent verbalization here as well these tones differed slightly from the known scale. The tones were modulated to achieve a fading in and fading out to provide a more comfortable listening. While the sound was played in via headphones a white square (width and length: 0.1114 rad) was shown on grey screen to make sure that the participants were focused on the task.

In the third group a combination of visual and auditive stimuli was presented. These combinations stayed the same within the block but differed between each block.

2.5 Analysis & Statistics

The results included the mean d-prime of each participant in each block and over all blocks as well as the mean criterion over all blocks and the reaction time for every presented stimulus. The experiment can be considered as a Signal-Detection experiment (Green & Swets. 1966). To find out how good the performance of each participant was, the d-prime, also called sensitivity index, was calculated. To get the d-primes, the values have to be z-transformed. After calculating the percentage of hits (there was a signal, which the participant detected) and the percentage of false alarm (there was no signal, but the participant said there is one) the d-prime can be calculated with the following equation:

$$d' = z(\text{hit rate}) - z(\text{false alarm rate})$$

The d-prime is a test statistic of the Signal Detection Theory which shows how well a person can differ between so called noise and a signal embedded within noise. As the formula shows it is not only important how many hits a person obtains but also how often the person wrongly assumes the existence of a signal. The average d-primes are obtained for every block and for the performance of each participant in general. The higher the d-prime the better a person can differ between noise and signal with noise. Besides, the Criterion is calculated for the whole performance. This test statistic is independent from the sensitivity and shows the bias of the participant. If the criterion is smaller than 0 the participant follows a liberal criteria. That means in an ambiguous situation the participant is rather saying that there was a signal. If the criterion is higher than 0 the participant says more often that there is no signal in an ambiguous situation and he follows a conservative criteria. The criterion helps to analyze whether and how strongly the outcome was influenced by the bias of the participants.

Excel was used to represent the results of the experiment and the questionnaire in a graph. To compare the means within the blocks and the means between the conditions a two-way mixed ANOVA (Analysis of variance) and within each condition a one-way repeated-measures ANOVA was conducted. The in-between factor was always the condition with 3 levels and the within-factor, if present, was the block with 5 levels. Another two-way mixed ANOVA was conducted concerning the response time of the participants. All ANOVAs were carried out with SPSS.

3 Results

Three groups of 12 people each had to perform a 3-back-task examining the performance of their working memory. Each group had to perform a slightly different task. One group was presented visual stimuli, another one auditive stimuli and the last group visual and auditive stimuli simultaneously. The 3-back-task consisted of 5 blocks with 60 stimuli each. Thus, the task performance was influenced by two independent factors: the condition which is a between-subject factor and the block which is a within-subject factor, as each subject was repeatedly measured. The experiment was conducted to find out if the working memory performance would be better when stimuli are presented bimodal compared to unimodal.

3.1 Influence of block and condition on the n-back task performance

The main measured variable was d-prime. The d-prime predicts how well the working memory of a participant functions by comparing the number of hits with the number of false alarms during each block of the experiment. The higher the d-prime, the better is the functioning of the working memory of a participant. To analyze if the d-primes of each condition and each block are significantly different a two-way mixed ANOVA was conducted. The analysis showed a significant difference between the d-primes of the measurements over all blocks ($F(4,132)=6.125$; $p < 0.001$) with a high partial $\eta^2=0.157$. Hence, the factor block had a positive influence on the working memory performance of the participants. For the first block the performance within the auditive group was relatively high but stays almost on the same level over all blocks, while the d-prime within the visual group increased clearly. The working memory performance within the bimodal group showed also a small increase (s. Fig. 3.1 and 3.2).

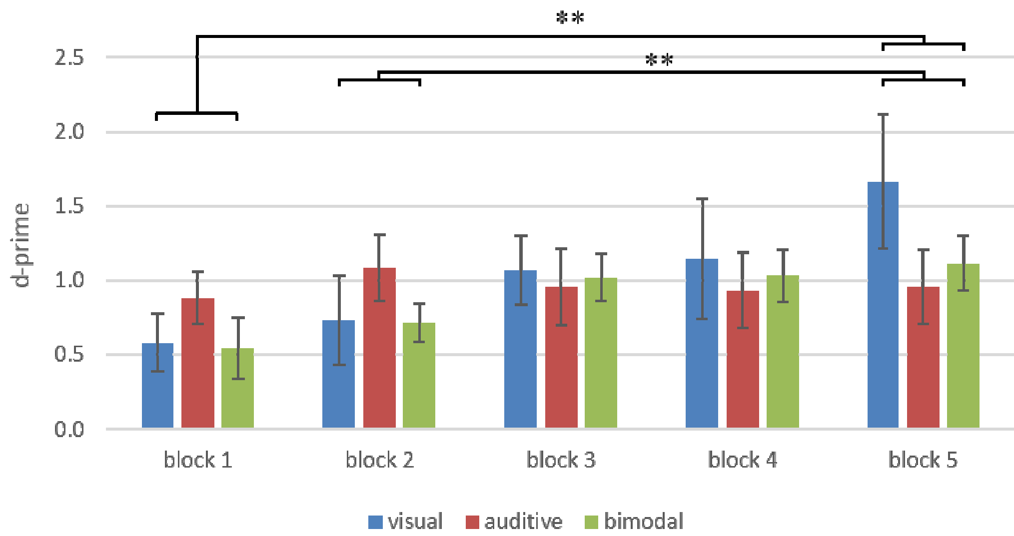

Fig. 3.1: Bar plot of mean d-prime values of every block in each condition. Each bar shows the mean d-prime for one block in one condition with n=12. Error bars show the SEM in negative and positive direction.

When looking at the post-hoc test of each measurement only block 1 and 5 ($p<0.01$) and 2 and 5 ($p<0.01$) were significantly different from one another.

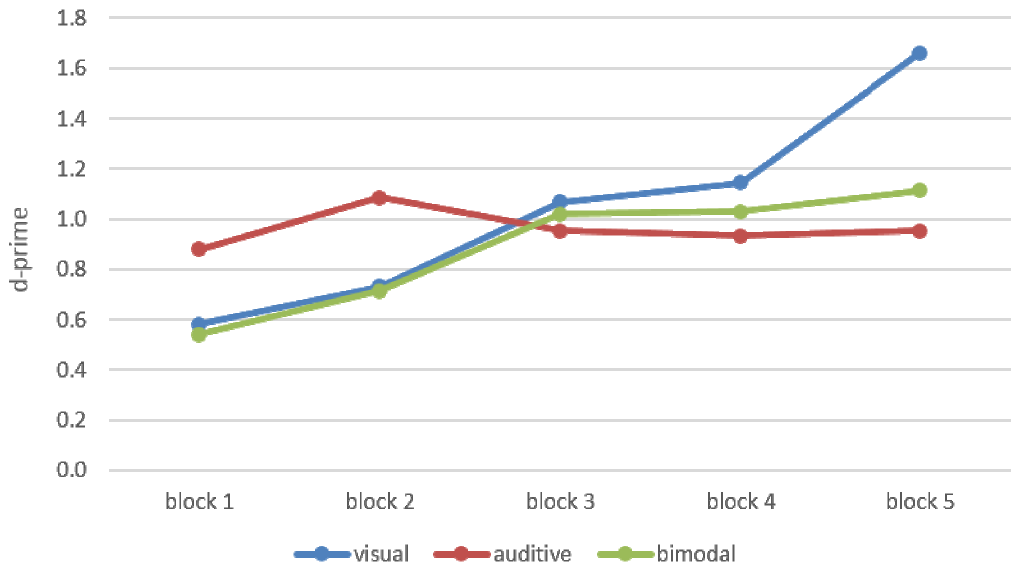

Fig. 3.2: The line graph shows the mean d-prime values of each block over the measurements. Every dot represents the mean d-prime of the participants in one block of one condition with n=12; Δd'visual=1.0810 Δd'auditive= 0.0723; Δd'bimodal= 0.5706

For the visual condition the steepest incline can be observed. The difference between the d-prime of the first and the last block is Δd-prime (visual) = 1.081. In the bimodal condition only a slight incline was shown (Δd-prime (auditive) = 0.0723). The d-primes in the auditive condition remained almost constant throughout the measurements (Δd-prime (bimodal) = 0.5706). The ANOVA did not indicate for any between-subject effect ($F(2,33)=0.125$; $p = 0.88$) so the factor condition had no significant influence on the working memory performance. The mean d-prime of the visual and auditive group was almost equal and the mean d-prime of the bimodal group was even a bit smaller (s. fig. 3.3).

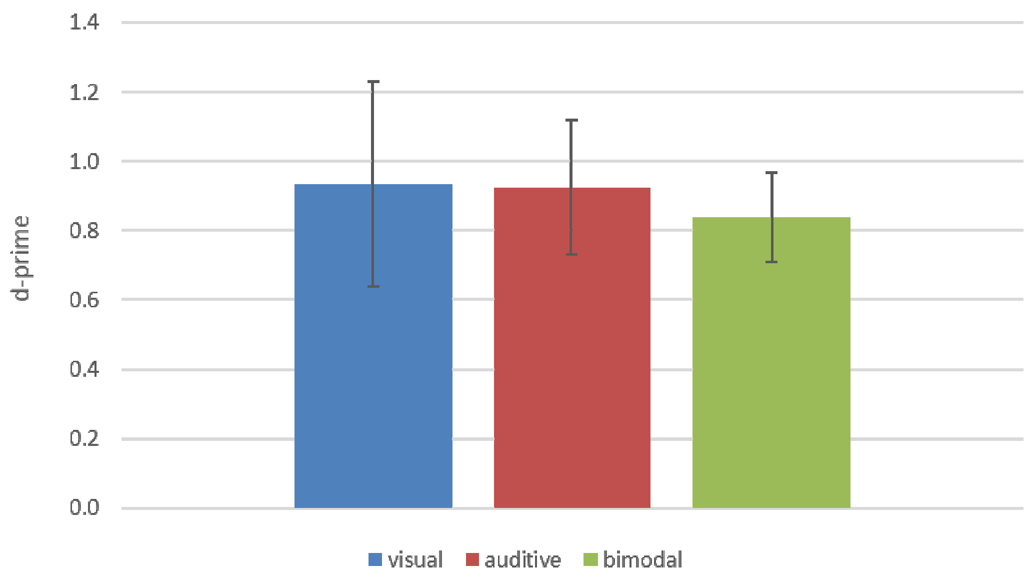

Fig. 3.3: Bar plot of mean d-prime values of each condition. No significance difference was found. Error bars indicate SEM.

3.2 Influence of block and condition on the reaction time

Another two-way mixed ANOVA was conducted to analyze whether the reaction time differs concerning condition and repeated measurements (blocks). The experimental software which runs the 3-back-task measured not only if the participants pressed the right or the left button of the mouse but also how long it took from presenting the stimuli to the pressing of the button. When no button was pressed the reaction time was registered as zero. All values put to zero were not used for calculating the mean reaction time of each block and the mean reaction time in general respectively. The reaction time within the visual group was lowest in all blocks and hence lowest in general (see fig. 3.4). The reaction time within the auditive and bimodal group do not differ significantly, but the reaction time within the auditive group was slightly higher compared to the reaction time of the bimodal group in general (s. Fig. 3.4 and 3.5).

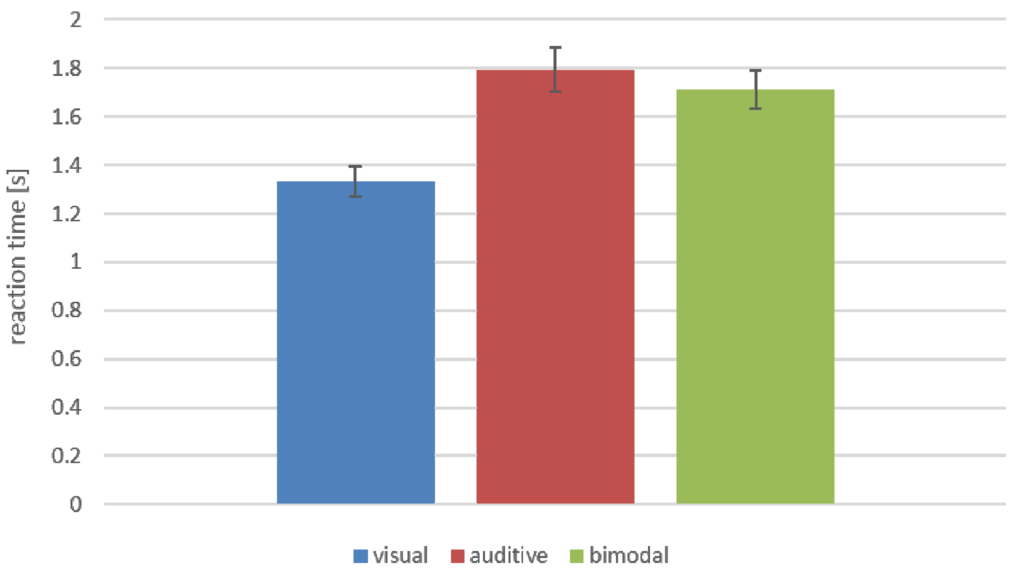

Fig. 3.4: The bar plot shows the mean reaction time for each condition averaged for all blocks. The error bar is the SEM in negative and positive direction.

The mean reaction time between the conditions differed significantly ($F(2,33)=12.162$; $p < 0.001$) with a partial $\eta^2=0.424$. The pairwise comparisons show significant difference between the visual and auditive ($p<0.001$) and visual and bimodal condition ($p<0.01$). The factor block showed also a significant difference ($F(4,132)=11.348$; $p<0.001$) with a partial $\eta^2=0.256$. The post-hoc tests showed significant differences between block 1 and 2 ($p<0.05$), 1 and 3 ($p<0.01$), 1 and 4 ($p<0.01$) and 1 and 5 ($p<0.01$).

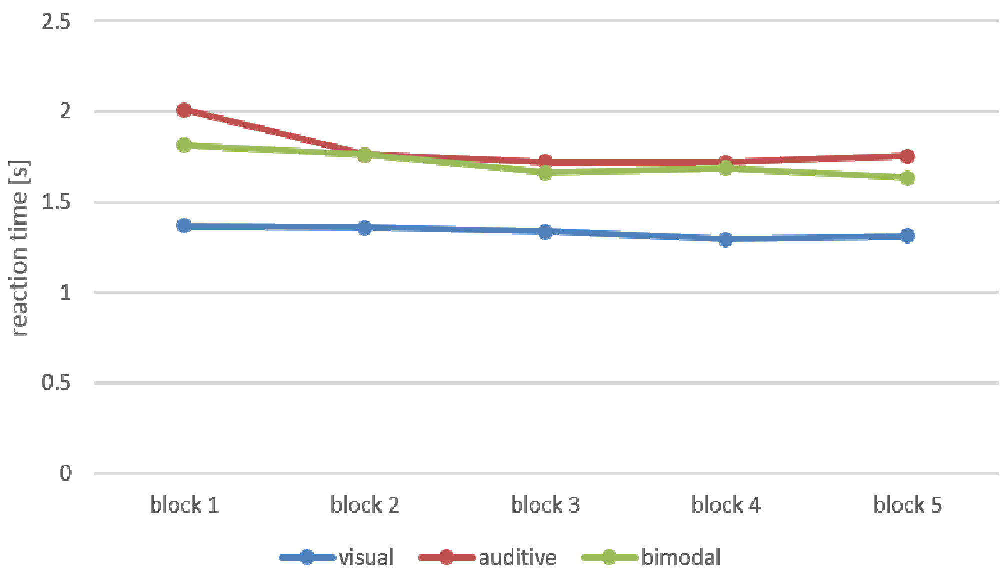

Fig. 3.5: The line graph shows the mean reaction time for each block over all measurements. Every dot represents the mean reaction time of the participants in one block of one condition with n=12.

3.3 Questionnaire of the participants

After the experiment each participant had to fill in a questionnaire to analyze his motivation and his self-assessment. The means for each answer were calculated. The answers in every group were quite similar. The motivation was above average for all groups. All stated that the task was difficult and most assumed that they did not do very well in the experiment. The main part of the participants knew what they had to do during the experiment though there is a small decrease from group one to group three (s.Fig. 3.6).

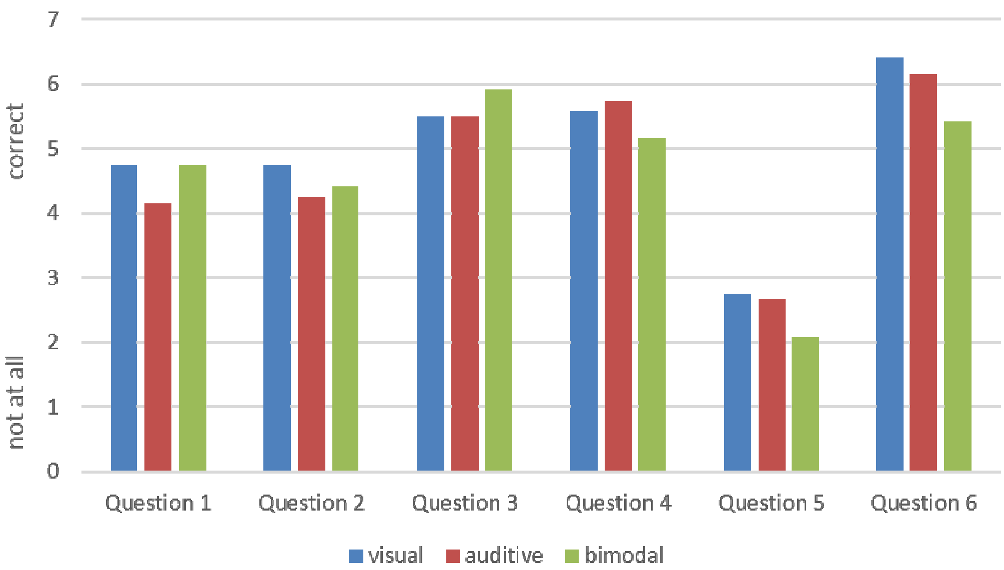

Fig. 3.6 : Results of the Questionnaire of the experiment. The participants could cross a number between 0 ('I do not agree at all with this statement') and 7 ('I totally agree with this statement'). The questions are listed below:

1 I was motivated during the experiment.
2 The experiment was fun.
3 I would participate again in a psychophysical experiment of this type.
4 The task was difficult for me.
5 I had the feeling that I did well in the experiment.
6 I was aware of what to do during the experiment.

The answers to question 7 were especially interesting within the bimodal group. Some participants said that they only concentrated on the sounds or the pictures and so probably ignored the other stimuli which were given simultaneously. This means they did not have a real advantage compared to the other two groups. One participant claimed trying to memorize the combination of picture and sound but was confused of the changing combinations over all blocks. One of the criticisms which were often voiced was the need for a feedback whether a button was pressed or not. A further point of criticism was the short presentation of the stimuli and within the auditive group the presentation of the white square. Some participants said it was more distracting than improving the concentration

3.4 Correlation of self-assessment and performance

Question 5 asked how the participants evaluated their performance after the experiment. When examining the relation between the self-evaluation and the actual performance of each participant there was found a correlation only in the visual condition (R^2=0.8677). Most participants in this condition graded their performance poorly which it also was. Only two participants graded themselves correctly above average (s. fig. 3.7). For the auditive and bimodal group no correlation between their self-assessment and their actual performance was found (s. fig. 3.8 and 3.9).

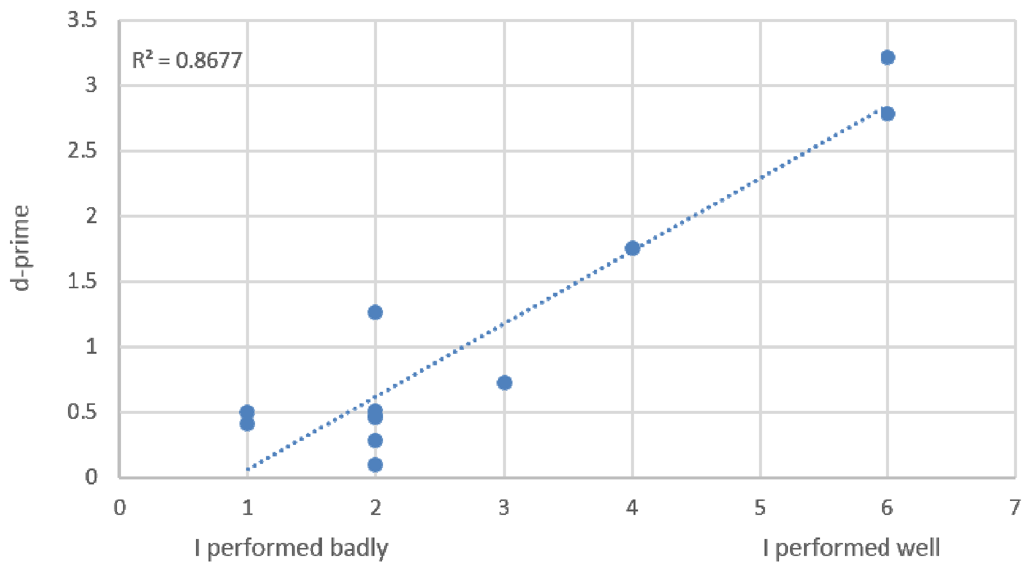

Fig. 3.7: Correlation plot between self-assessment and task performance (d-prime) in the visual group. Self-assessment and actual performance show a high correlation (R^2=0.8677).

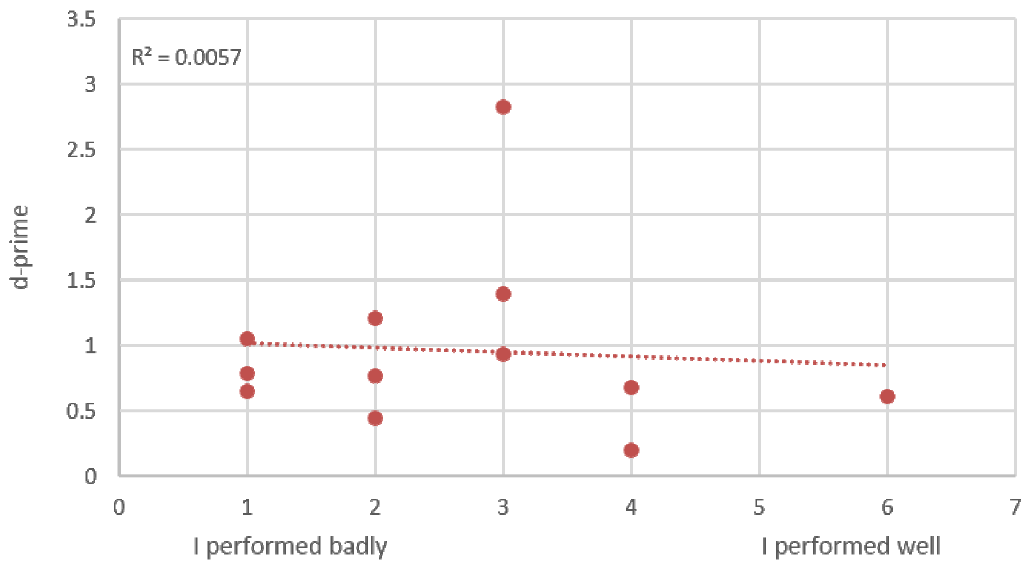

Fig. 3.8: Correlation plot between self-assessment and task performance (d-prime) in the auditive group. Self-assessment and actual performance show a high correlation (R^2=0.0057).

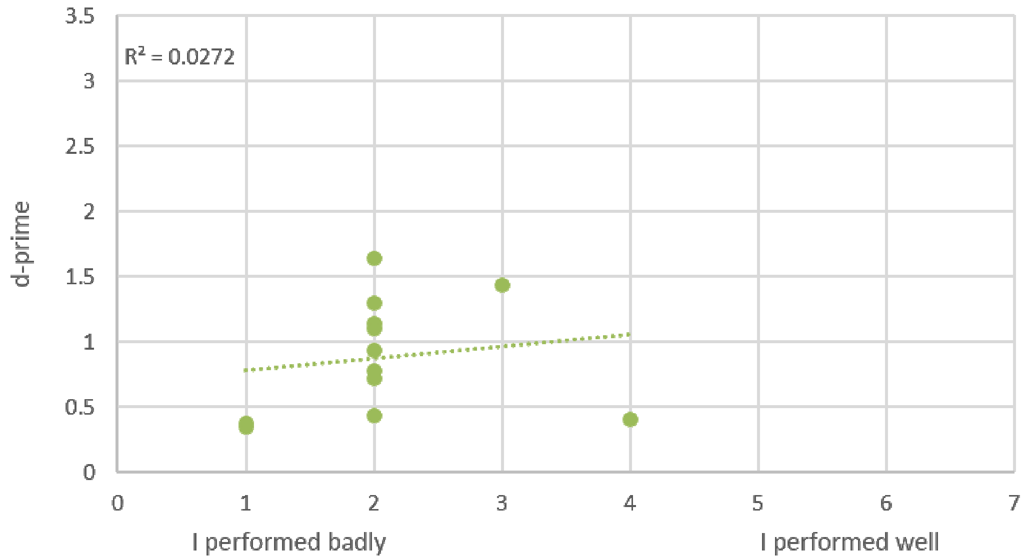

Fig. 3.9: Correlation plot between self-assessment and performance within the bimodal group. Self-assessment and actual performance show a high correlation (R^2=0.0272).

4 Discussion

The aim of this study was to prove an advantage for bimodal presentation of stimuli in a working memory task compared to unimodal presentation. For this a 3-back task was conducted. Subsequently the results of this study are discussed.

4.1 The influence of modality on memory performance

An overall modality effect, i.e., an improvement of bimodal stimulation on working memory performance, could not be identified. Thus, with this work, the hypothesis about a potential advantage of bimodal stimulation and processing regarding working memory representation has to be rejected.

This result contrasts previous findings from other research. Paivio and Thompson (1994) conducted a study with a similar design to prove the functional independence of memory codes. In their first experiment items were presented either bimodal (picture and sound) or unimodal (picture or sound). Participants of the group with the bimodal condition were able to recall more items than participants within the unimodal condition. The experiment did not include a n-back task but free recall. The participants had as much time as needed for recalling, so there was no time pressure. Additionally the stimuli were not abstract but well known items, e.g., a cow or a bell. These circumstances made the task more easily to solve than a 3-back task with abstract stimuli and time pressure (Thompson & Paivio, 1994). A study of Goolkasian and Foos (2005) examined an advantage of the bimodal presentation of items as well. The items were presented in different ways: either as picture, printed word, spoken word or a combination of two of these three conditions. As a result they found a better recall performance when the items were presented bimodal, i.e. a spoken word combined with a picture or printed word (Goolkasian & Foos, 2005).

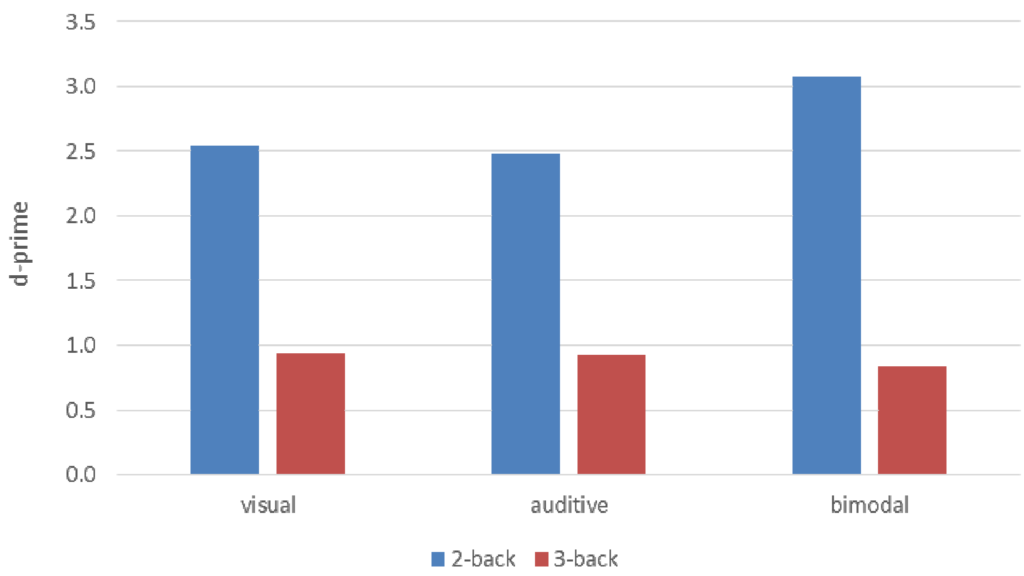

Fig. 4.1: Bar graph of mean d-prime values of each group in 2-back and 3-back task.

The bachelor thesis of Marisa Diehl (2013) supports the idea of a bimodal advantage as well. The current study was based on that one of Marisa Diehl and the design was exactly the same except the number of participants and the n-back task. The task of the former bachelor thesis was a 2-back task which turned out to be too easy (participants showed a high number of hits and a very low one of false alarms). But by changing the task into a 3-back task it could have been too difficult. While the d-prime values in the 2-back task were between 1.5 and 4.0 that one in the 3-back task were only between 0.5 and 2.0 (s. Fig. 4.1). The stimuli were created very abstract to prevent verbalization and pre-knowledge from long-term memory and thus, memorization was very difficult. When conducting a 3-back task, the participant had to compare the presented stimulus with that one three steps before. Furthermore, for the purpose of later comparisons, the two stimuli between those two stimuli have to be memorized as well. Thus, the task got much more difficult in two ways when increasing the n from 2 to 3: there were (one) more stimuli to remember for a longer period of time. All this together made it more difficult to maintain and retrieve the required information to solve the task correctly (Diehl, 2013).

4.2 The learning of unimodal and bimodal stimuli over blocks

During the course of the experiment (the 5 consecutive blocks) participants of the visual and bimodal group showed an improvement of the working memory performance, i.e. increase of d-prime values. Such a learning effect was expected as usual consequence of the repetitive implementation of the same working memory task. Jaeggi et al. (2011) conducted a spatial n-back task with school children. The active control group had to answer for example general knowledge questions. Jaeggi et al. found a significant improvement in the experimental group after one month of training but no improvement in the active control group. This shows that performance on working memory tasks can be improved simply by repetition (Jaeggi et al., 2011).

The learning rate in the visual and bimodal group was similar between block 1, 2, and 3. For the last two blocks the visual group showed a higher learning rate compared to the bimodal one. The reason of the slower increase of the working memory learning rate within the bimodal group compared to the visual group could have the following reason: there were 12 pictures and 6 tones in general. For every block in the visual group 6 different pictures were chosen and for every block another selection of 6 pictures out of the 12 were presented. This happened for the bimodal group as well, but as there were only 6 different tones in general, the combination of sound and picture changed after every block. This may have been very distracting for the participants and thus more difficult than the simple change of the pictures in the visual group. Indeed, participants reported the fact that each block was presented with new combinations of pictures and sounds as confusing.

The absence of learning of working memory performance within the auditive group was a bit surprising. The working memory performance starts on a high level (about 0.9) in the first block compared to the other two groups (about 0.6). But while the working memory performance of the visual and bimodal group increased, it remained more or less constant on the same level till block 5 within the auditive group. An explanation for this could be that participants within the visual and bimodal group developed and improved a strategy to memorize and recall the stimuli more easily. Basically participants had to remember three stimuli and when a new one was presented they could forget the oldest one. In the auditive group the stimuli were very hard to remember on their own so it might be easier to memorize the tones as a “melody”. Changing the whole melody when a new tone was presented was harder than just forgetting the oldest picture in the visual group for example. Such differences between the learning curves of the conditions were not found for the identical 2-back task (Diehl, 2013). There, while starting on different levels for block 1, the increase in performance was nearly identical for all modality condition. Unfortunately, the contrasting result in the actual 3-back study cannot be explained entirely.

4.3 The reaction time

The mean reaction times of the visual group showed a significant lower value than the ones of the auditive and bimodal group. These results may be related and support the visual dominance, i.e., the visual modality dominates the perception when multimodal cues are available. An example of visual dominance was shown in an experiment of Ehrsson et al. (2004). Participants had to sit in front of a table with a rubber arm lying to the right of the participant and next to a screen. The right hand of the participant was hidden behind this screen. Now the experimenter touched the fingers of the real and the rubber hand with a brush simultaneously for some times. After a while the participant considered the rubber arm as his own. Another example of visual dominance over auditory information is the already mentioned ventriloquism effect. This visual dominance is not only present in perception but also in memory. Posner (1967) showed this in his study. When participants had to recall proprioceptive and visual information they acted as if only the visual information had been present (Posner, 1967). In another study of Posner, Nissen, and Klein (1976) this visual dominance effect was analyzed as well. As a result they postulated that visual information does not alert the organism as fast as input from other modalities and thus the organism paid more attention to the visual modality. Another effect which was found is that the switching of attention from one modality to another takes some time. This might be the explanation for the different mean reaction times between the visual group and the auditive and bimodal group, respectively. Participants of the visual group had only to focus on visual input while watching the screen. In the bimodal group visual and auditive input was provided so participants may have switched their attention from the visual to the auditive modality as they did not perceive the two stimuli as connected. In the auditive group participants watched the screen while waiting for the next auditive stimulus. The changing of the screen from a white square on grey background to a grey screen may have served as a visual cue for the task which was some times in the focus of attention or at least turned the attention away from the auditive modality. This switching of attention from the visual to the auditive and back took time which could explain the higher reaction time in those two groups (Posner, Nissen & Klein, 1976).

4.4 Correlation of self-assessment and working memory performance

After finishing the task every participant had to fill in a questionnaire. Besides motivation it asked for a self-evaluation of the participant's performance. The value which each participant specified was compared to the actual performance of the task. For the auditive and bimodal group no correlation could be found while the visual group showed a relatively high correlation between self-evaluation and measured performance. This may explain the low learning rate and therefor the unchanging performance during all 5 blocks of the auditive group. It seems that participants of the auditive group had a very bad feeling about their performance. In the bimodal group the participants evaluated themselves worst of all (eight out of the twelve self-evaluations were found with 2) although a learn effect did occur. Maybe the task was rated as more complex by them than it actually was and thus evaluated so badly.

4.5 Future prospects

The aim of this study was to find an advantage in working memory performance for bimodal presented stimuli when compared to unimodal presentation. This could not be proved for several reasons. The main reason was probably the difficulty of the task. The lack of a learning effect in the auditive and bimodal group may serve as an incentive for changing the design of the study slightly. Some participants quoted that the presence of a feedback would be helpful to cope with the task. Another suggestion was to begin with a slightly easier preliminary test to get used to the design and to integrate a longer pause between the stimuli. Within the auditive group participants said that the white square which was shown on the screen while the tone was played was more distracting than helpful. Another reason for the rather bad performance may also have been the small spacing between the tones. For the bimodal group another problem was added: After each block the combination of tone and picture changed. This made the task probably more difficult than the other two as it was more confusing.

To prove whether a bimodal advantage exists, the difficulty level of the working memory task should be situated between the 2-back and the 3-back task. This may be accomplished with a 3-back task with stimuli which are easier to recall.

5. Acknowledgment

First of all I want to thank my supervisor Dr. Gregor Hardiess for all his help and support. I also want to thank Prof. Mallot and the members of the cognitive neuroscience research group for their suggestions and advices. My thank goes as well to Lisa Hoffmann, Eva Köhnert and Zeljko Grljusic for checking my thesis for mistakes. Finally I would like to thank all people who took part in the experiment.

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7. Appendix

A.1 Distribution of hits

trial number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
block 1				x		x				x	x				x
block 2				x			x						x		x
block 3					x		x			x		x		x	
block 4					x		x				x		x		
block 5				x				x	x		x				

trial number	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
block 1		x		x		x			x				x		
block 2		x				x					x	x			
block 3			x		x		x					x		x	
block 4	x	x	x			x				x	x				x
block 5	x		x					x	x		x				

trial number	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
block 1			x				x	x			x				x
block 2				x			x						x	x	
block 3			x	x			x				x	x			x
block 4	x			x		x		x		x		x			
block 5	x						x		x		x			x	

trial number	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
block 1		x		x		x			x				x		x
block 2			x		x				x				x		
block 3				x	x				x		x				x
block 4		x		x		x			x	x				x	x
block 5			x			x		x				x			

A.2 Questionnaire

Fragebogen Experiment

Dieser Fragebogen enthält Aussagen zu Verhaltensweisen beim Lösen der Aufgabe. Wir bitten Sie, für jede Aussage anzuzeigen, inwieweit Sie der Aussage zustimmen. Die Möglichkeit zur Ablehnung bzw. Zustimmung hat die folgende Form:

trifft gar nicht zu 1 2 3 4 5 6 7 trifft voll und ganz zu

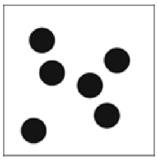
Bitte markieren Sie für jede Aussage diejenige Position durch Einkreisen, die dem Grad ihrer Zustimmung am besten entspricht. Markieren Sie bitte die Mittelposition (4), wenn Sie weder zustimmen noch ablehnen.

1 Während des Experiments war ich motiviert.	1	2	3	4	5	6	7
2 Das Experiment hat mir Spaß gemacht.	1	2	3	4	5	6	7
3 Ich würde wieder an einem psychophysikalischen Experiment dieser Art teilnehmen.	1	2	3	4	5	6	7
4 Ich fand die Aufgabe schwierig	1	2	3	4	5	6	7
5 Ich habe das Gefühl im Experiment gut abgeschnitten zu haben.	1	2	3	4	5	6	7
6 Während des Versuches war mir klar, welches Ziel ich verfolgen sollte	1	2	3	4	5	6	7
7 Hatten Sie zur Lösung der Aufgabe eine bestimmte Strategie? Wenn ja, welche?							
8 Haben Sie Anmerkungen zum Versuchsaufbau/Versuchsdurchführung oder Probleme? (Pros, Cons)							

A.3 Instructions (visual, auditive, bimodal)

<u>3- back Task (visuell)</u>

1. <u>Aufgabe</u>



- Während des Versuches wird in jedem Block eine Reihenfolge von 6 verschiedenen Mustern (Bsp. siehe links) gezeigt.
- Bei jedem präsentierten Muster müssen Sie entscheiden, ob es das gleiche ist wie das, das drei Stellen vorher präsentiert wurde.
- Ist das Muster <u>**identisch** mit demjenigen drei Stellen zuvor, muss die **linke Maustaste**</u> gedrückt werden. Falls das Muster <u>**nicht identisch** ist, muss die **rechte Maustaste**</u> gedrückt werden.
- Es muss also immer eine Maustaste gedrückt werden. Dies kann während der Muster-Präsentation passieren, oder auch in der Pause danach. (Bsp: 1 4 3 1 3 … Bei der Präsentation der 4. Stelle muss die linke Maustaste gedrückt werden, da drei Stellen davor auch eine 1 gezeigt wird, bei der 5. Stelle dagegen die rechte Maustaste, da drei Stellen vorher eine 4 präsentiert wurde)

2. <u>Ablauf</u>

- Sie absolvieren insgesamt 5 Blöcke mit jeweils 60 Mustern. Die verschiedenen Blöcke sind jeweils untereinander abgeschlossen. Innerhalb jedes Blocks werden andere 6 Muster gezeigt.
- Zu Beginn jedes Blocks wird in der Mitte des Bildschirms ein Kreuz 2 Sekunden angezeigt, welches Sie fixieren müssen, bis die Sequenz des 3-back Tasks automatisch beginnt.
- Wenn ein Block beendet ist, wird dies auf dem Bildschirm angezeigt. Der nächste Block kann begonnen werden, indem eine beliebige Taste gedrückt wird.
- Nach jedem Block kann nach Bedarf eine Pause eingelegt werden.

Bei Fragen wenden Sie sich bitte an den Versuchsleiter.

Bitte führen sie die Aufgabe so genau wie möglich aus… viel Spaß! ☺

<u>**3- back Task (auditiv)**</u>

1. <u>Aufgabe</u>
   - Während des Versuches wird in jedem Block eine Reihenfolge von 6 verschiedenen Tönen über einen Kopfhörer eingespielt.
   - Sie müssen bei jedem eingespielten Ton entscheiden, ob er der gleiche ist wie der, der drei Stellen vorher eingespielt wurde.
   - Ist der Ton <u>**identisch** mit demjenigen drei Stellen zuvor muss die **linke Maustaste**</u> gedrückt werden. Falls der Ton <u>**nicht identisch** ist, muss die **rechte Maustaste**</u> gedrückt werden.
   - Es muss also immer eine Maustaste gedrückt werden. Dies kann während der Ton-Einspielung passieren, oder auch in der Pause danach. (Bsp: 1 4 3 1 3 … Bei der Präsentation der 4. Stelle muss die linke Maustaste gedrückt werden, da drei Stellen davor auch eine 1 gezeigt wird, bei der 5. Stelle dagegen die rechte Maustaste, da drei Stellen vorher eine 4 präsentiert wurde)

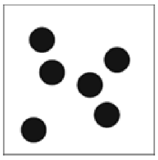
2. <u>Ablauf</u>
   - Sie absolvieren insgesamt 5 Blöcke mit jeweils 60 Tönen. Die verschiedenen Blöcke sind jeweils untereinander abgeschlossen.
   - Zu Beginn jedes Blocks wird in der Mitte des Bildschirms ein Kreuz 2 Sekunden angezeigt, welches Sie fixieren müssen, bis die Sequenz des 3-back Tasks beginnt.
   - Wenn ein Block beendet ist, wird dies auf dem Bildschirm angezeigt. Der nächste Block kann begonnen werden, in dem eine beliebige Taste gedrückt wird.
   - Nach jedem Block kann nach Bedarf eine Pause eingelegt werden.

Bei Fragen wenden Sie sich bitte an den Versuchsleiter.

Bitte führen Sie die Aufgabe so genau wie möglich aus… viel Spaß! ☺

3- back Task (audiovisuell)

1. Aufgabe



- Während des Versuches wird pro Block eine Sequenz von 6 verschiedenen Tönen (über Kopfhörer eingespielt) und Mustern (auf dem Bildschirm) simultan präsentiert (Muster s. links). Jedes Muster ist hierbei mit einem bestimmten Ton assoziiert. Es gibt 6 verschiedene Ton-Muster Paare, wobei jeweils ein Paar für 2 Sekunden (gefolgt von einer 1-Sekunden Pause ohne Stimulus) präsentiert wird. Die 6 verschiedenen Ton-Muster Paare pro Block identisch, variieren jedoch für jeden einzelnen Block.
- Sie müssen bei jedem präsentierten Ton-Muster Paar entscheiden, ob es das gleiche ist wie das, welches drei Stellen vorher präsentiert wurde.
- Ist das Ton-Muster Paar **identisch** mit demjenigen Stellen zuvor, muss die **linke Maustaste**. Falls das Ton-Muster-Paar **nicht damit identisch** ist, muss die **rechte Maustaste** gedrückt werden.
- Sie müssen also bei jedem gezeigten Ton-Muster Paar eine Maustaste drücken. Dies kann während der Stimulus-Präsentation passieren, oder auch in der Pause danach. (Bsp: 1 4 3 1 3 Bei der Präsentation der 4. Stelle muss die linke Maustaste gedrückt werden, da drei Stellen davor auch eine 1 gezeigt wird, bei der 5. Stelle dagegen die rechte Maustaste, da drei Stellen vorher eine 4 präsentiert wurde)

2. Ablauf

- Sie absolvieren 5 Blöcke mit einer Sequenzlänge von jeweils 60 Ton-Muster Paaren. Die verschiedenen Blöcke sind jeweils untereinander abgeschlossen. Innerhalb jedes Blocks werden andere 6 Ton-Muster-Paare präsentiert.
- Zu Beginn jedes Blocks wird in der Mitte des Bildschirms ein Fixationskreuz für 2 Sekunden angezeigt, welches Sie fixieren müssen, bis die Sequenz des 3-back Tasks beginnt.
- Wenn ein Block beendet ist, wird dies auf dem Bildschirm angezeigt. Der nächste Block kann begonnen werden, indem eine beliebige Taste gedrückt wird.
- Nach jedem Block kann nach Bedarf eine Pause eingelegt werden.

Bei auftretenden Fragen wenden Sie sich bitte an den Versuchsleiter.

Bitte führen Sie die Aufgabe so genau wie möglich aus…

Viel Spaß! ☺