PROCESSING OF TONAL INFORMATION IN WORKING MEMORY

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ABSTRACT

Three experiments dealing with the short-term retention of short sequences of tonal information in working memory are presented. As a conceptual framework, the multi-component-model of working memory (Baddeley & Logie, 1999) is used. This model includes at least two independent subsystems for the processing of visual/spatial and auditory/phonetic information. Two experiments using the dual-task-paradigm address the question whether the phonetic subsystem of working memory is responsible for the processing of tonal information as well as verbal information. A third experiment was carried out in order to test whether a central feature of the phonetic subsystem, i.e. the distinction between a passive phonetic store and an active rehearsal mechanism, plays a role in the processing of tonal information. In this experiment the retention interval for sequences of tonal information was varied. Additionally, effects of participants' level of musical training were analyzed.

Results show that there is a functional overlap in working memory mechanisms involved in the processing of tonal and verbal information. Thus, characteristics described in the field of processing of verbal information can be applied to the processing of tonal information as well. It is concluded that the multi-component-model of working memory can be used in the field of music psychology in order to understand basic mechanisms in the processing of tonal information.

1. BACKGROUND

The concept of working memory plays an important role in understanding the human memory system. Working memory, which can be described as *on-line-cognition* (Baddeley & Logie, 1999) is responsible for keeping a limited amount of information activated and making it available for conscious information processing. Typical tasks which rely heavily on working memory performance are short-term retention of information or manipulation of information. Capacity of working memory is limited and information fades rapidly if not subjected to active control mechanisms.

It is considered as useful to discriminate at least two independent subsystems in working memory, i.e. the so-called *visual-spatial scetchpad* and the *phonological loop* (Baddeley, 1997). The latter was originally put forward to describe processing of auditory components of verbal information (Baddeley & Hitch, 1974; Gathercole & Baddeley, 1993). The phonological loop is conceptualized as a dual system: a passive phonetic store holding information for about 2 seconds, and an active (albeit automatically activated) rehearsal-process serving to maintain decaying representations in the phonetic store, and thus prolonging the activated state.

During the last years several findings have questioned the language-specificity of the phonological loop. There is growing evidence that other classes of auditory information, such as rhythm information or duration information is also processed by the phonological loop (e.g. Grube, 1996, 1999). To date, it remains unclear whether tonal information (or music in general) is processed by the phonological loop as well. Alternatively, it has been suggested to add an independent *tonal loop* as another subsystem to the working memory model (Berz, 1995, Pechmann & Mohr, 1992).

Further empirical evidence is necessary to find out to which amount the processing of tonal and verbal information is relying on the same working memory mechanisms. This will help to decide whether there is one common subsystem for tonal information processing and processing of auditory components of verbal information, or two independent subsystems.

2. AIMS

The first aim was to test whether processing of tonal information is affected by concurrent processing of verbal information. Using a dual-task paradigm, the primary task was short-term retention of tonal material while the secondary task was a verbal task, namely articulatory suppression. Additionally, a non-auditory (visual) task was included as a secondary task in order to show that there is no unspecific decrease in working memory performance caused by secondary tasks of any kind. Under the assumption that tonal and verbal information is processed by independent subsystems of working memory, there should be no substantial interference between simultaneous processing of verbal and tonal information. If, on the other hand, the phonological loop is responsible for verbal as well as tonal information processing, performance on tonal information processing should be affected by concurrent processing of verbal information. Such a result would not be compatible with the assumption of an independent tonal loop subsystem.

A second aim was to have a closer look at the distinction between the passive phonetic store and the active rehearsal mechanism in a short-term retention task with tonal material. If processing of tonal material relies primarily on the same working memory-mechanisms as the processing of other classes of auditory information, performance should be based on two factors: the accuracy of the representation of tonal information in the phonetic store and the ability to delay the decay of information by active rehearsal.

Variation of the retention interval can be used to discriminate between the passive storage system and the active rehearsal process. As assumed, the passive phonetic storage system holds information for up to two seconds (Baddeley, 1997). Performance on a retention task with a short retention interval

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of up to 2 seconds relies primarily on the representation in the phonetic store. If the retention interval is longer than 2 seconds, the rehearsal mechanism becomes more important. Performance on a retention task then reflects the ability to maintain an accurate representation of tonal information based on active rehearsal.

3. METHOD

A sequence of three experiments was conducted. In the first two experiments participants had to perform on short-term retention tasks with verbal as well as tonal information while concurrently performing on verbal and non-auditory secondary tasks. The third experiment included a variation of the retention interval for tonal sequences.

3.1. Experiment 1

Participants performed on four experimental conditions, each consisting of 24 trials. In the two tonal conditions (with concurrent secondary task / without concurrent secondary task) each trial consisted of two tonal sequences which were presented with a retention interval of 10 seconds. The tonal sequences consisted of two sinus tones taken from the range between A3 and E5, which were presented consecutively for 250 ms with an ISI of 500 ms. Participants' task was to decide whether both sequences were identical or different. Conditions included 50 % trials with same and different sequences in randomized order. Tone distances used within each trial were minor triad, major triad, and quart. In trials with different sequences one of the two tones of the second sequence was varied by one half-tone.

The design of the trials in the verbal condition was analogous to the tonal condition. In the verbal condition, the sequences consisted of five consonants which were presented consecutively on a monitor. In trials with different sequences the order of two consonants in the second sequence was varied. Both verbal and tonal conditions were presented with and without a verbal secondary task. The verbal secondary task consisted of articulatory suppression, which means that participants had to articulate a word (e.g. "twentyfive") presented to them on a monitor consecutively during the 10-second retention interval. 22 students of University of Hildesheim participated in experiment 1 (age M = 26.1, SD = 4.96).

3.2. Experiment 2

Experiment 2 employed longer tonal sequences consisting of five consecutive tones chosen from the range between G2 and A3. This time, sequences were generated using MIDI-Software and were presented as "Acoustic Grand Piano"-MIDI-tones. Again, each condition consisted of 24 trials with 50 % same and different sequences, respectively. In trials with different sequences one tone of the second sequence was varied by either one or two half-tones. The verbal conditions were identical to experiment 1, except that stimuli were presented auditorily. Included were two additional conditions in which participants performed the tonal and verbal primary task, respectively, while concurrently performing on a visual secondary task. This secondary task consisted of the presentation of series of visual symbols. Participants had to decide whether two consecutive sequences were identical. 36 students of University of Hildesheim participated in experiment 2 (age M = 23.2, SD = 2.44).

Following experiment 1 and 2 participants filled out a short questionnaire to assess their level of musical training. The questionnaire included questions about the amount of practical and theoretical musical training, the average time spent making music, and knowledge in music theory.

3.3. Experiment 3

Experiment 3 included four conditions, in which the duration of the retention interval was varied. Duration of the retention intervals was 2 seconds, 5.2 seconds, 10 seconds, and 14.8 seconds. Again, each condition consisted of 24 trials with 50% same and different sequences and participants had to decide whether two sequences of a trial were identical or different. Tonal sequences used were the same as in experiment 2. 36 students of University of Hildesheim participated in the experiment (age M = 25.2, SD = 2.89).

4. RESULTS

Results from Experiments 1 and 2 show that short-term retention for verbal as well as for tonal information decreases significantly under articulatory suppression. This suggests a strong influence of the verbal secondary task (articulatory suppression) on a primary task with tonal information as well as verbal information. In both experiments there was no substantial difference between the amount of impairment in the tonal and verbal conditions.

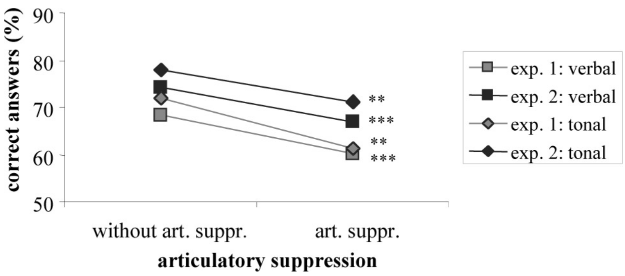

Fig. 1: Effect of articulatory suppression on short-term retention of verbal and tonal information (results from experiments 1 and 2). **: $p < .01$; ***: $p < .001$.

The visual secondary-task included in experiment 2 had no impairing effect on the performance on short-term retention of neither verbal nor tonal information. The slight decrease in both conditions shown in Fig. 2 is non-significant.

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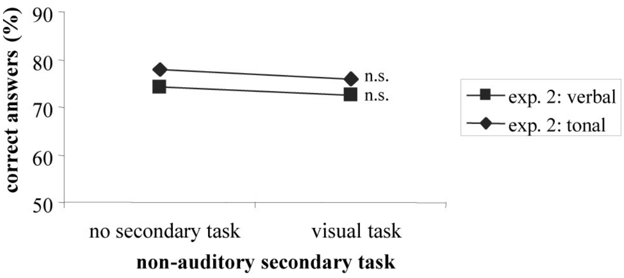

Fig. 2: Short-term retention of verbal and tonal information under a visual secondary-task (results from experiment 2)

Based on the information given in the questionnaire participants were divided into two groups: One *trained group* which included participants who were able to play an instrument and had had at least six years of formal training and/or substantial knowledge in music theory. A second group with *participants with no musical training* who did not meet these criteria. Differences between these two groups were analyzed in order to test whether the decrease in performance under articulatory suppression is influenced by musical training. If, in the tonal condition, only the performance of participants without musical training is impaired by concurrent articulatory suppression, this would be a strong indicator of different working memory mechanisms underlying processing of tonal information, depending on the amount of musical training. However, results did not support this notion. Fig. 3 indicates a substantial decrease in both groups: There is a general impairment in short-term retention for tonal material under articulatory suppression. While the non-significance of the difference found for participants with no musical training in experiment 2 can be attributed to the generally low level of performance even without articulatory suppression, the more important finding is the decrease found in participants with musical training.

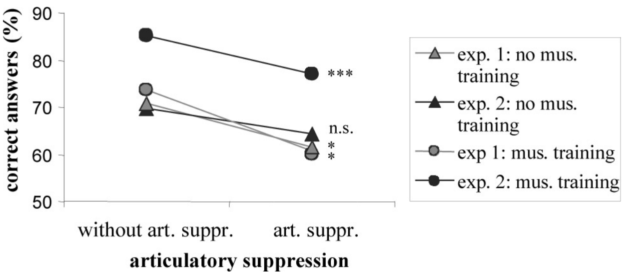

Fig. 3: Effect of articulatory suppression on short-term retention of tonal information for participants with no musical training and participants with musical training (results from experiments 1 and 2). *: $p < .05$; ***: $p < .001$.

No differences between participants with musical training and participants with no musical training were found in the verbal conditions, indicating no general superiority in working memory performance for participants with musical training.

Another issue was to investigate to which extent performance on a short-term retention task with tonal material depends on the accuracy with which tonal material is initially encoded in the phonetic store (of the phonological loop). Results from experiment 3 were divided into two groups of participants: Based on retention performance on the longest retention interval (14.8 seconds), which places the highest demands on the working memory functions involved, a median-split was performed. Thus, two sub-groups resulted: One which succeeded quite well in short-term retention over the longest interval (labeled as *accurate representation*) and one which showed rather poor performance (labeled as *inaccurate representation*). When comparing results from these two groups under the shortest retention interval (2 seconds), it becomes clear that there is already a substantial difference in performance (see Fig. 4), which can be attributed to a more accurate initial representation. It can be concluded that participants differ regarding the ability to accurately represent tonal stimuli directly after presentation.

The second question addressed in experiment 3 was whether the accuracy of a representation constantly declines with increasing duration of the retention interval. Alternatively, it is possible that there is no decrease of accuracy; instead, the rehearsal mechanism conservates the initial auditory image represented in the phonetic store at a constant level of accuracy, no matter whether it is an accurate or fuzzy image. Fig. 4 shows that there is no decline in performance in the group with a more accurate representation as a function of increasing duration of retention intervals. In participants with a less accurate representation there is also no decrease in performance over the first three retention intervals, which means that there is a refreshing of the auditory image in the phonetic store without further loss of information. Only under a retention interval of more than 10 seconds performance further decreases.

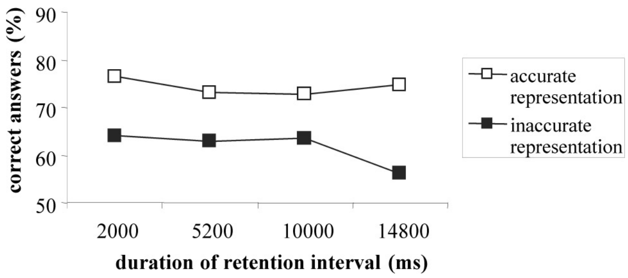

Fig. 4: Performance on short-term retention of tonal information for retention intervals of different duration. Accurate representations are represented stable over increasing durations; less accurate representations are represented stable for up to 10 seconds.

5. CONCLUSIONS

Results of two experiments clearly show an impairing influence of a verbal secondary task on tonal information processing as a primary task. The amount of impairment is similar to that of a verbal secondary task on a verbal primary task. Because concurrent processing of visual information leads to no interference, results indicate that processing of tonal information and of the auditory aspects of verbal information is based on the same working memory mechanisms. In terms of the multi-component-model of working memory (Baddeley & Logie,

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1999), this can be interpreted as evidence that processing of tonal information is also done by the phonological loop. Results do not support the suggestion of an additional subsystem specialized for tonal information (e.g. Berz, 1995). These results are in correspondence with earlier findings demonstrating that the phonological loop is not specific for processing of verbal information.

Additional support for this view is supplied by the lack of differences between result patterns of participants with and without musical training. In both groups, articulatory suppression (concurrent processing of verbal information) led to a substantial decrease in short-term retention of tonal information of comparable magnitude. Even if participants had a certain amount of musical training, there is no evidence that tonal information is processed independently from verbal information and, thus, no support for a specialized subsystem for processing of tonal information. Obviously, verbal and tonal information is processed within one common subsystem instead of parallel processing of tonal and verbal information.

It is important to notice that the task used in the reported experiments included the processing of tonal information as a primary task in a dual-task paradigm. This implies that tonal information has to be encoded, represented and held active in working memory. In contrast, experiments using tonal information as a secondary task only provide information on the access of tonal information to the phonological loop in general, but allow for no further insights on the actual processing (encoding and maintaining) of tonal information in working memory.

Experiment 3 provides further insight into how both aspects of the phonological loop, the phonetic store and the rehearsal mechanism, function together when tonal information is processed: results indicate that a substantial amount of individual differences in performance on a short-term retention task with tonal information is caused by the accuracy of the initial representation in the phonetic store. On the other hand, the rehearsal process mainly serves to maintain the representation in the phonetic store, no matter how accurate the auditory image is. Results show that this process of refreshing is basically not subjected to a substantial loss of information, at least up to retention intervals of 10 seconds in duration. Results are in line with findings indicating that the accuracy of a representation as well as the ability to prevent fading play an important role in processing of auditorily presented verbal information. Moreover, both components of the phonological loop, i.e. the phonetic store and the rehearsal mechanism, contribute to the processing of tonal information as well. The rehearsal mechanism for verbal information, described as "inner speech", obviously can switch to a kind of "inner singing", thus maintaining representations of tonal information in working memory.

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