Memory for Tonal Pitches

A Music-Length Effect Hypothesis

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One of the most studied effects of verbal working memory (WM) is the influence of the length of the words that compose the list to be remembered. This work aims to investigate the nature of musical WM by replicating the word length effect in the musical domain. Length and rate of presentation were manipulated in a recognition task of tone sequences. Results showed significant effects for both factors (length and presentation rate) as well as their interaction, suggesting the existence of different strategies (e.g., chunking and rehearsal) for the immediate memory of musical information, depending upon the length of the sequences.

Key words: **working memory; length effect; music; pitch tone**

Introduction

Working memory (WM) is a temporary storage system that allows maintaining and manipulating information in order to perform complex cognitive tasks, such as comprehension, learning, and reasoning.[1] WM is limited in time and in capacity. Verbal memory span can be expressed in terms of either number of items or total duration of the sequence. Thus, a span measured in terms of number of items is likely to depend on the articulatory duration of the items.[1]

Few studies have tried to compare the processing of musical stimuli to the elaboration of verbal information in WM. Deutsch[2] developed a classical comparison paradigm of single tones in which subjects were asked to decide whether two tones, presented at a 5-s interval, were identical or not. It has been observed that performance is less accurate with inter-stimulus selective interference (interpolated tones) compared to nonselective one (interpolated digits). Accordingly, the existence of a specialized memory system for tonal pitch has been suggested.[2] Pechmann and Mohr[3] proposed the existence of a tonal loop that can be conceived of as a "sibling" of the phonological loop and suggested that the tonal loop comprises a tonal storage and a tonal rehearsal component. On the basis of this work and on Baddeley's WM model,[1] Berz[4] proposed a theoretical model that includes an additional and separate component: a "music memory loop" containing a musical store and a control process based on musical inner speech.

In the present study, we aimed at further exploring the nature and characteristics of musical WM by replicating the "word length effect" in the musical domain. It has been shown that verbal capacity for list of words is

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modulated by the articulatory time of the words, with faster articulatory words producing longer spans and vice versa.[5] This phenomenon is called the *word length effect* and it appears to reflect an underlying process of subvocal rehearsal.

Classical theories attributed this effect to the articulation rate[5] or, alternatively, to the number of items and their attributes.[6] It has been shown that, in analogy to apparent motion in visual perception, a rapid presentation of a sequence of tones enhances the segmentation process.[7] In music, in contrast to language, the length of the perceived units may vary, depending on the rate of presentation, and ranging from a single tone in slow rates of presentation to a group of tones in fast rates. A musical melody is not perceived as a sequence of isolated tones, but rather as a stream of events that unfolds over time such that tones form together larger units. In their book, Lerdahl and Jackendoff[8] suggested several grouping preference rules that help to segment a sequence of tones into its constituent subgroups. These include formalized Gestalt principles, such as principles of proximity, more abstract formal concerns, such as symmetry, and principles relating to pitch stability. Therefore both length of sequence and rate of presentation are expected to affect performance in the musical domain, with better performances for short compared with long sequences—because of a smaller memory load—and for fast compared with slow rate of presentation because of a better process of segmentation.[7]

Experiment 1

Method

Participants

Eight undergraduate students, without any formal musical training, from the University of Pavia participated in the experiment for academic credit (one male and seven females, mean age = 24.1 years).

TABLE 1. Experimental Conditions in Experiment 1

	Presentation	
Conditions	Slow	Fast
Sequence		
Short	6 tones/1000 ms	6 tones/500 ms
Long	9 tones/1000 ms	9 tones/500 ms

Material and Procedures

Participants were presented with pairs of isochronous tone sequences. In every trial participants listened to a pair of isochronous tone sequences presented to them via headphones, and had to perform a same/different task. Sequence tones were within an octave range in C major. The order of notes in the sequence was pseudo-random with some constrains: no repetition of the same note or a pattern of two or more notes was allowed; the same note could not be repeated inside a single sequence in half or more of its positions; a movement in passes for three or more consecutive notes was not allowed. Half of the sequences were the same. In the other half one of the intermediate tones was changed, introducing a deviation of semitone or tone. Original contour was preserved. The position, the note, and the direction of changing were all counterbalanced across the sequences of every block.

In each trial, sequences could be “short” or “long” (6 or 9 tones, respectively) and could be presented at two different rates: “slow” (1000-ms tone duration, no gap) and “fast” (500 ms). Overall length was chosen in order to stay within the limits of WM capacity, both in terms of number of items and total duration.[9] Thus, four categories of stimuli were obtained, as shown in Table 1. Every category included 60 pairs of sequences for a total of 240 trials.

Results and Discussion

A 2 × 2 (length × presentation rate) repeated-measures analysis of variance (ANOVA) was performed on the percent of the correct responses for each condition. A

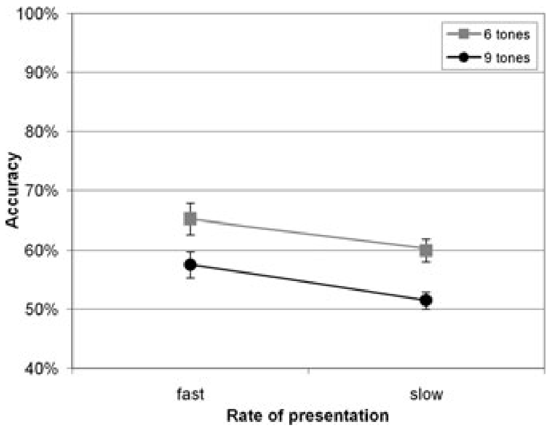

Figure 1. Experiment 1: mean accuracy is presented as a percentage of the function of presentation rate (slow 1000 ms/fast 500 ms) and sequence length (6 versus 9 tones). Error bars represent standard errors. Chance level is at 50%.

significant main effect was observed for length [$F(1,7) = 8.88$, $P < 0.05$, $\eta^2 = 0.56$] and for presentation rate [$F(1,7) = 10.04$, $P < 0.05$, $\eta^2 = 0.59$], indicating that performance was better for short than for long sequences and for fast than for slow sequences (Fig. 1). These findings suggest that both length and rate of presentation have an effect on performance. Moreover, the interaction was not significant [$F(1,7) = 0.07$, $P = 0.8$ n.s., $\eta^2 = 0.01$] and the two effects seem to combine in an independent fashion. However, the overall level of performance was low; therefore a second experiment was devised with shorter sequences.

Experiment 2

Method

Participants

Nine new subjects (undergraduate students, one male and eight females, mean age = 25) participated in this experiment.

Material and Procedures

Material and procedure were identical to those in Experiment 1, except the length of the sequences, which were manipulated such that short sequences were composed of 4 tones and the long sequences were composed of 6 tones. The four categories of stimuli are shown in Table 2.

TABLE 2. Experimental Conditions in Experiment 2

Conditions	Presentation: Slow	Presentation: Fast
Sequence		
Short	4 tones/1000 ms	4 tones/500 ms
Long	6 tones/1000 ms	6 tones/500 ms

Results and Discussion

A 2 × 2 (length × presentation rate) repeated-measures ANOVA showed a significant main effect for length [$F(1,8) = 204.2$, $P < 0.001$, $\eta^2 = 0.96$]. In addition, a significant interaction between length and duration was found [$F(1,8) = 5.9$, $P < 0.05$, $\eta^2 = 0.43$]. In order to identify the origin of the interaction between length and duration, the differences due to both factors were analyzed separately. For long sequences, performance with a fast presentation was significantly more accurate than with slow presentation [$F(1,8) = 5.5$, $P < 0.05$, $\eta^2 = 0.41$]. For short sequences no such effect was observed [$F(1,8) = 2.7$, $P = 0.1$ n.s., $\eta^2 = 0.25$]. When considering rates of presentation, short sequences were remembered more accurately than long sequences both for slow rates of presentation [$F(1,8) = 42.3$, $P < 0.001$, $\eta^2 = 0.84$], as well as for fast rates of presentation [$F(1,8) = 6$, $P < 0.05$, $\eta^2 = 0.43$]. Figure 2 shows that performance was better for short sequences, but this effect was maximized for slower rate of presentation. Comparing these data to Experiment 1, we see that duration tended to show an opposite pattern: long sequences produced better performances with faster rates, while short sequences do not show such an effect and were remembered slightly better with slower presentation rates (Fig. 2).

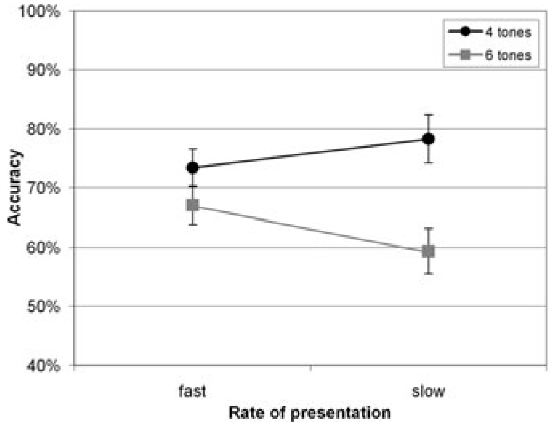

Figure 2. Experiment 2: mean accuracy is presented as a percentage of the function of presentation rate (slow 1000 ms/fast 500 ms) and sequence length (4 versus 6 tones). Error bars represent standard errors. Chance level is at 50%.

General Discussion

These results provide the first demonstration of a particular "length effect" for tone sequences. Indeed, recognition of musical information is affected by both number of items and rate of presentation. Interestingly, these two factors interact with each other such that long sequences are better recognized with a faster rate of presentation, whereas in short sequences fast rate of presentation does not enhance recognition. Whereas for long sequences the fast rate of presentation may enhance a process of segmentation[7] and chunking, thus reducing WM load, short sequences seem to show a reverse pattern, although the data are not statistically significant. It is possible to hypothesize that the strategies used to remember short sequences rely more on an "item-by-item" approach to the melody. In other words, because the sequence is short, there is no real need to group, thus losing the advantage of a fast presentation rate. By contrast, an item-by-item approach will benefit more from a slower rate of presentation, by leaving more time for a possible covert rehearsal process to intervene.

These findings cannot be explained by taking into account the classical explanation of the word length effect in the verbal domain.[1,5,6] More research is needed in order to understand whether our results are either due to the existence of a functionally different WM system for tones than for words, or due to perceptual mechanisms (such as grouping) that may operate in a more salient or influential way in musical domain, or the result of different cognitive strategies for verbal and musical items. In addition, in order to understand the strategies that underlie the musical short-term memory a further study will have to manipulate directly the possibility of creating chunks in the to-be-remembered material.

Conflicts of Interest

The authors declare no conflicts of interest.

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