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Sound rhythm effects on cardiac parameters

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The aim of this study was to find out effects of simple sound rhythms on cardiac parameters of listeners. The rhythms used differed in tempo and intensity, while changes in cardiac parameters (R-R intervals and their variability) were used to assess the effects on the subjects. Experimental design was 3 x 2 within group factorial experiment. Three different levels of tempo (60, 200 and 400 BPMs), and two intensity levels (40 and 80 dB) were used. Eleven subjects participated in the experiment, which consisted of six experimental situations, interpolated with silence situations. Complex effects of different situations were found on cardiac parameters. When sequential effects were eliminated by the use of linear regression, rhythm effects on cardiac parameters were obtained, with a tendency of a decrease in heartbeat frequency, which was more prominent during listening to more intensive and slower rhythms. Heartbeat variability tended to decrease during listening any rhythm.

The most often used indicators of the amount of stress in studies on stress are changes in functioning of vegetative system. A great number of researchers give advance to these indicators in their studies because of the unreliability and poor validity of introspective reports, and also because of the use of applicable and reliable electronic devices designed for accurate measurement of the physiological reactions.

Different parameters of the cardiac activity have been used as dependent variables in recent laboratory research of different sources of stress such ass values of R-R intervals and variability parameters of R-R intervals.

A large body of research has confirmed the diversity in direction and amount of change of cardiac frequency in specific situations. Lacey (1972), for example, discriminates stimulus expectation and signal detection tasks from the so-called mental tasks. According to this author, deceleration of cardiac frequency, i.e. increase of R-R intervals, occurs in situations which demand observation and response to external stimuli, while cardiac frequency increases in situations which demand mental activity. Lacey explains this decrease of cardiac frequency in stimulus expectation situations as increased sensitivity to stimuli and as readiness of the organism to response quickly and adequately. Deceleration of pulse includes reduction of the activity of baroreceptors and decrease of neural noise, which interferes with information processing. Having this hypothesis as their starting point, some studies (Kaliterna, 19 Gregov et al., 1996) have shown that in external stimulus expectation situation deceleration of pulse, increasing with the period of expectation, occurs. Some other studies (Takšić & Kunac, 1991) which included mental arithmetic tasks (adding of one-digit and three-digit numbers) and simple reaction time have confirmed basic points of Lacey's hypothesis. On the other hand, his hypothesis about effects on cardiac frequency in tasks that involved both stimulus expectation and mental activity has not been confirmed empirically (Gregov et al., 1996).

In some studies (Sgoutas-Emch et al., 1994; Delahanty et al., 1996; Sloan et al., 1991) that included mental arithmetic tasks as stressors, the increase of pulse immediately after performance of these tasks has been found. Some other studies (Benschop et al., 1995) found increase of pulse immediately after the performance of the laboratory task which consisted of problem solving. Tasks were unsolvable and participants were not instructed in that matter.

It seems that heart frequency, as indicator of the current state of participant, reflects effect of stress, emotions and different internal and external factors. Some other studies have pointed to the fact that heart frequencies should not be considered as valid parameter defining the amount of mental load. Results of these studies have shown that changes in variability of R-R intervals are more valid indicators of changes in mental load than values of R-R intervals, i.e. cardiac frequency. Changes in R-R interval variability have proved to be valid and discriminative indicator of metal load.

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The procedure of determining heartbeat variability is based on the measurement of time intervals between successive R picks of ECG. This variability is also called sinus-arrhythmia, since it is conditioned by variations in depolarization of sinoatrial node, which regulates cardiac frequency. When calm, R-R intervals are relatively irregular, and they can vary between 500 and 1200 ms, while during the mental effort they become more regular as a function of the difficulty of the task. The reason for this occurrence is not completely clear. It seems that key role for this belongs to different respiration reflexes and to the activity of vagus (parasimpaticus) connected to sinoatrial node (Manenica, 1980). According to Sayers (1973), changes of R-R intervals variability are connected to fluctuations of blood pressure, thermal regulation and respiration activity.

This method, which does not interfere with participants' task, was used in some studies that tried to detect the effects of mental load in tasks of different type and difficulty. Kalsbeek (1971) was one of the first to realize that the regularity of R-R intervals in binary choice task was greater with the greater load, in terms of information theory, while heart frequency did not change significantly as a function of mental load. Some other results (Kalsbeek & Sykes, 1970; Mulder, 1988; Lee & Park, 1990) have shown increase in regularity of R-R intervals as a function of mental load increase. Kalsbeek (1973) states that if the mental load by a task reaches the level that causes decrease in R-R intervals variability, variability will increase again unless decrease in load occurs.

When determining heartbeat arrhythmia, similar results occurred with participants who performed easy repetitive industrial type task (Manenica, 1974). Increased number of components that reached the assembly line in unit of time and which were supposed to be put together by participants was followed by greater regularity of R-R intervals while heart frequency remained unchanged.

In several studies, effects of the imposed rhythm of work were tried to be detected by use of different parameters of heartbeat intervals variability. Manenica (1977) found longer and more variable R-R intervals during work in conditions of imposed work rhythm, which was identical to non-imposed rhythm work in other instances. Although these results point to lesser stress during imposed rhythm work, Charnock and Manenica (1978) have found significantly different R-R intervals spectrograms in conditions of imposed and non-imposed work rhythm. Interference of externally imposed rhythm of work and biological rhythm were observed on spectrograms of R-R intervals.

Furthermore, Manenica and Krošnjar (1990) found that variability in R-R intervals decreased as a function of increase in load in labyrinth task solving. However, variability increased as a function of increase in information load with memory capacity tasks. Increase in R-R interval variability in meaningless syllables repetition tasks and counting backward tasks was explained by changes in motor respiration component, while pronouncing words. Several studies (Sayers, 1973; Hirsh & Bishop, 1981; Veltman & Gaillard, 1998; Brown et al., 1993) have also shown that changes in respiration variability can significantly affect changes in variability of heart activity. When it comes to differences between work with imposed and non-imposed rhythm when solving numerical and perceptive tasks, results of this study show greater R-R intervals variability during imposed rhythm work, which was 10 percent more intensive than in non-imposed rhythm work conditions.

Music, as rhythmic stimulus, can motivate, move or excite people. Accordingly it might be said that sound rhythms could act as stressors to organism. Since no references in literature were found on this subject, preliminary study was carried out with the aim of finding some evidence for these kinds of effects.

The aim of this study was to investigate evidence of simple sound rhythm effects on listeners' cardiac parameters. It is reasonable to assume that listening of sound rhythm can present stress to organism, which may change the listener's cardiac rhythm due to changes in tempo and/or intensity of a simple sound rhythm. Also, listening to sound rhythm could present mental or even emotional load to listener. This would affect cardiac variability parameters making them lower.

METHOD

Participants and experimental design

The study included 11 female participants, psychology students of age between 18 and 20. Experimental design was 3 x 2 within subjects design. Two factors were included: Tempo and Intensity of sound rhythm. Tempo factor included three levels, and Intensity factor included two levels. Complete experiment consisted of six experimental

Table 1

Scheme of experimental design

		TEMPO of sound rhythm		
		60 BPM	200 BPM	400 BPM
INTENSITY of sound rhythm	approximately 40 dB			
	approximately 80 dB			

BPM – Bits Per Minute
dB – decibels

situations (Table 1). Each experimental situation was preceded by silent control situation.

Every participant passed through all six experimental situations, which sequence was rotated according to the Latin square principle.

Equipment and materials

Equipment included two computers with appropriate software for sound rhythms of various tempo and intensity. Stereo phones that led sound to listeners' ears were used to apply six different sounds. Sound rhythms consisted of low frequency beats, similar to bass drum beats. The PowerLab system together with chest electrodes was used for recording of cardiac parameters.

Procedure

Every listener was seated, individually, in quiet room, with earphones on her ears, which were plugged into the computer that generated sound rhythms. Via the electrodes on the chest, listeners' cardiac parameters were recorded during the experimental sessions.

Prior to the beginning of experimental session, every listener was instructed to relax and was told that after the initial silence, sequences of various sound rhythms, separated by periods of silence would appear. Listener was also instructed to listen the rhythms *actively* and *carefully*.

Recordings of listener's cardiac R-R intervals started immediately, during the first 5-minute period of silence, as well as the six proceeding experimental situations, which lasted 5 minutes each. Silent pauses were interpolated between experimental situations and they lasted 5 minutes, as well. Last experimental situation was also followed by silent pause. Listener's ECG was recorded continuously for 65 minutes during all experimental situations and, also, during all silent pauses.

ANALYSIS AND DISCUSSION

Dependent variables that were analyzed were R-R intervals – periods of time between two heart beats - and also, two variability parameters of R-R intervals, i.e. standard deviations and DM indexes.

DM index is calculated by formula

$$DM = \frac{\Sigma\,|RR_i - RR_{i-1}|}{N-1}$$

where RR_i is current R-R interval, and RR_{i-1} is preceding R-R interval.

Figure 1 shows average values of R-R intervals as they were recorded, depending on sequence of silent pauses and sequence of experimental situations. That means that this is exactly how situations went for every listener, regardless of their rotation.

The increasing trend of average R-R intervals is clearly visible as a function of situations' sequence, or as a function of time, respectively. Only successive silent pauses were taken (M) for analysis of that trend. This is because in Rhythm situations (X) other effects besides mentioned

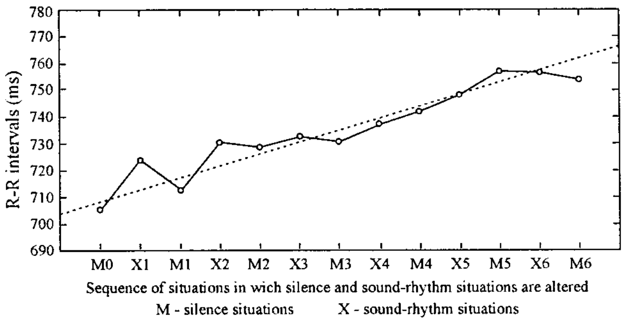

Figure 1. Average values of R-R intervals as a function of sequence of situations. Trend: $r = 0{,}98$; $t(5) = 10{,}628$; $p<0.01$. Regression function: $Y = 4{,}28*X + 703{,}43$.

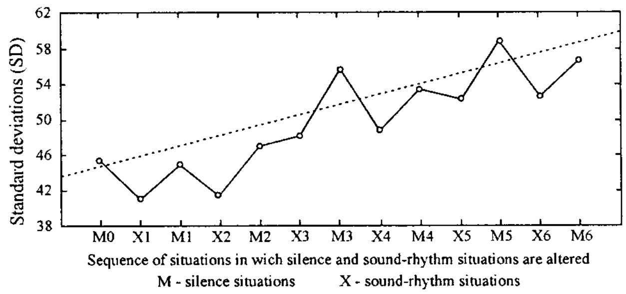

Figure 2. Average values of standard deviations (SD) as a function of sequence of situations. Trend: $r = 0{,}91$; $t(5) = 4{,}98$; $p<0.01$. Regression function: $Y=1{,}16*X + 43{,}58$.

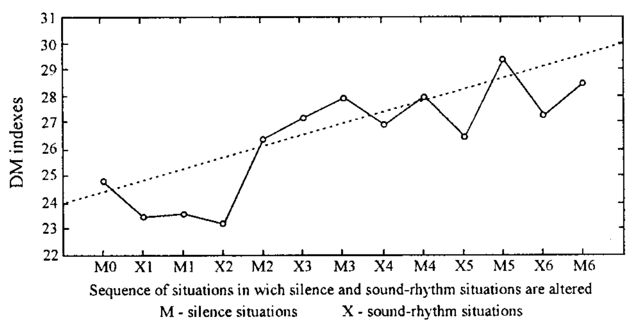

Figure 3. Average values of DM indexes as a function of sequence of situations. Trend: $r = 0{,}91$; $t(5) = 4{,}96$; $p<0.01$. Regression function: $Y = 0{,}43*X + 23{,}93$.

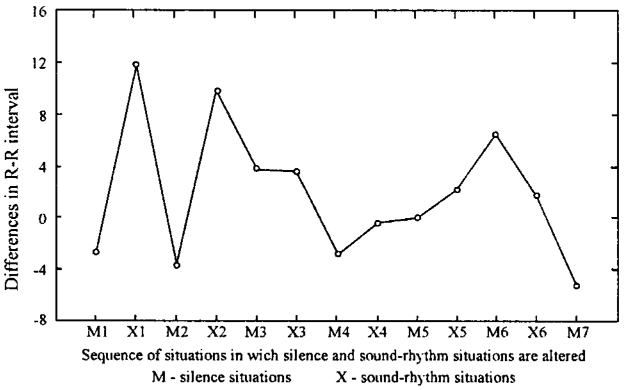

Figure 4. Average differences of R-R intervals from results estimated by trend.

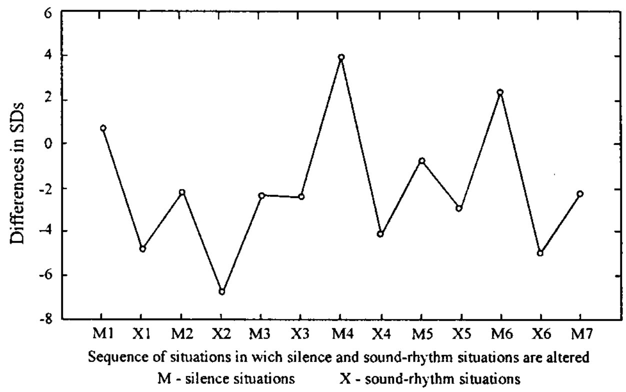

Figure 5. Average differences of standard deviations from results estimated by trend.

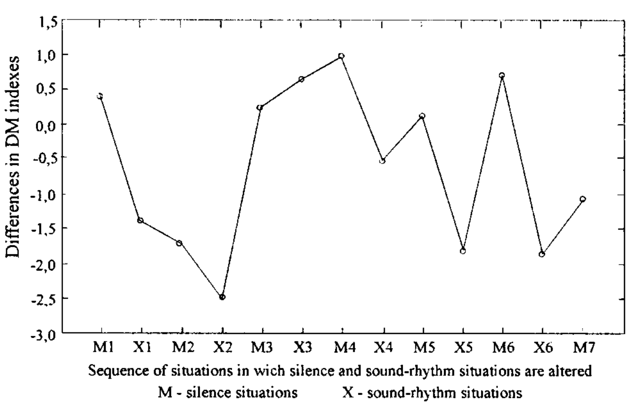

Figure 6. Average differences of DM indexes from results estimated by trend.

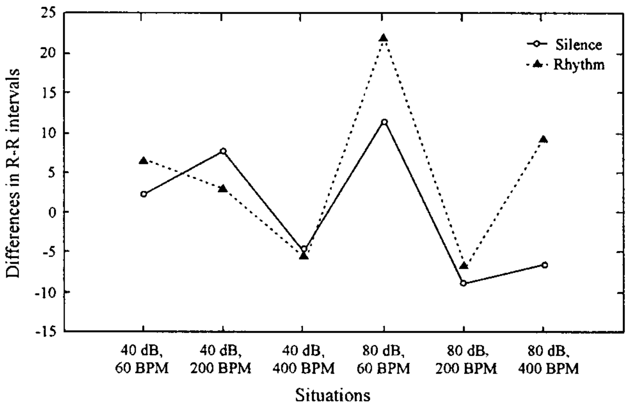

Figure 7. R-R intervals during silence and during situations of listening to rhythms of various tempo and intensity.

trend could be present. Coefficient of correlation between sequence of situations and recorded R-R intervals was high and significant. Also, regression function was calculated.

Trend of significant increase of R-R intervals as a function of situations' sequence is, in fact, trend of increase of R-R intervals as a function of time. Apparently, this effect could be attributed to the experimental habituation. Listeners were sitting quietly and listening to rhythms or silence during period of 65 minutes. That procedure had to have an effect on listeners' relaxation that resulted with increase of R-R intervals, or with progressively lower heart frequency, respectively.

As it can be seen, we have the same case with both parameters of heartbeat variation – standard deviations and DM indexes. Figures 2 and 3 present average standard deviations and DM indexes as a function of situations' sequence.

As it can be seen, similar trend of increasing variables appeared again as a function of time. Significance of trend is represented with high and significant correlation coefficients and regression functions.

Evidence about existence of this kind of trend makes further analysis more complicated. Before the main analysis, influence of trend has to be taken out. Apparently, trend carries covariance into all situations. But, as it was mentioned at the beginning, sequences of situations were rotated according to Latin square principle. Hence, trend influences differently certain experimental situation for each listener.

In further analysis, regression equations were used to calculate estimated value for each situation for each listener. By use of the estimated values and the obtained values, the differences between them were calculated. Finally, average values of those differences are shown in Figure 4, for R-R intervals and in Figures 5 and 6, for standard deviations and DM indexes, respectively.

Trend is eliminated. It is obvious that there is a tendency of increase in R-R intervals in situations of sound-rhythms' listening in comparison to situations of silence, and also a tendency of decrease in heartbeat variability parameters.

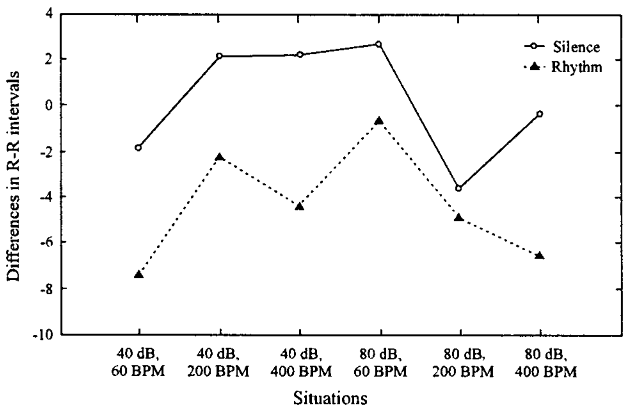

Figure 8. Standard deviations during silence and during situations of listening to rhythms of various tempo and intensity.

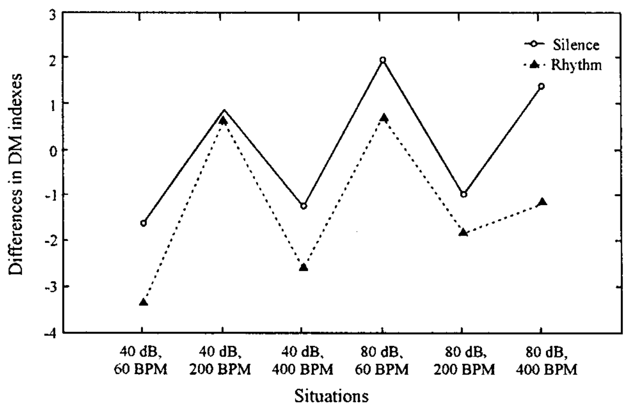

Figure 9. DM indexes during silence and during situations of listening to rhythms of various tempo and intensity.

Further analysis includes specific experimental situations. This is the main part of analysis. Figure 7 shows average results of differences for R-R intervals.

There are average results for each experimental situation, which are depicted by dotted line, and for each preceding situation of silent pause, which are depicted by uninterrupted line. It is apparent that when two situations are compared, R-R intervals tend to increase when listening to more intensive rhythms, of 80 dB.

Similarly, both parameters of cardiac variability tend to decrease when listening to any rhythm as is clearly visible in Figures 8 and 9. Three-way analysis of variance on R-R intervals shows significant effect for factor Tempo (Figure 10).

It seems, by now that general effect of sound rhythms' listening is slowing cardiac rhythm down. However, surprisingly and contrary to expectations, the strongest effect on slowing the cardiac rhythm down, had the slowest rhythm among sound rhythms of 60 BPM, if compared to faster ones of 200 and 400 BPM. Possible reason for this could be that this rhythm was close to average cardiac rhythm (of approximately 70 BPM) and the interference might have slowed heart rate. Other two sound rhythms were probably too fast to create that kind of interference. This effect is similar to Manenica's (1977) evidence that externally imposed rhythm (of work in his study) could entrain cardiac rhythms. Other explanations can include relaxing, or even, hypnotizing effect of simple sound rhythms amongst which the slower rhythms had stronger effect. Other effect found is 2-way interaction between Silence-Rhythm factor and Intensity factor shown in Figure 11.

This suggests that only loud rhythms of 80 dB had effect on R-R intervals' increase but that was not the case with less loud rhythm of 40 dB. The effect of less loud rhythms was not clear, which could be investigated in some future research.

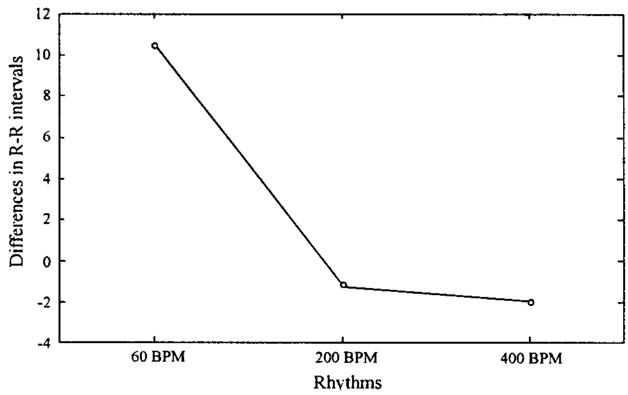

Figure 10. Average R-R intervals for three levels of TEMPO Main Effect, $F(2,20)=4.69; p<0.0214$.

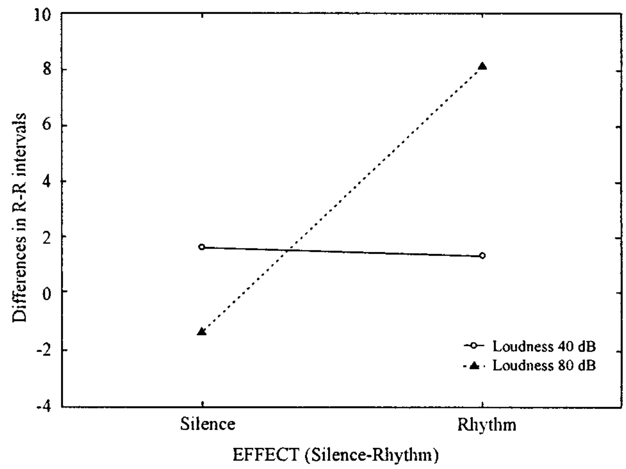

Figure 11. Average R-R intervals for 2-way interaction (Silence-Rhythm) X (Intensity), $F(1,10)=9.77; p<0.0108$.

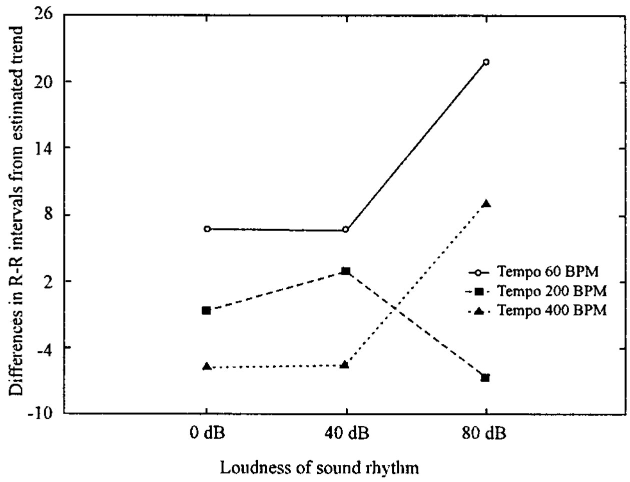

Figure 12. R-R intervals as function of intensity and tempo of sound rhythms.

More concise results of R-R intervals can be seen in Figure 12 which shows changes of cardiac rhythms as a function of sound-rhythms tempo and intensity. Again, it is apparent that the strongest effect was obtained for slow and loud sound rhythm.

Analysis of variance on both cardiac variability parameters – standard deviations and DM indexes – showed significant effects on Silence-Rhythm factor (Figure 13 for standard deviations and Figure 14 for DM indexes). Variability of heartbeats tends to decrease when listening to sound rhythms.

Heartbeats' variability decrease is typical for mental load (Kalsbeek & Sykes, 1970; Mulder, 1988; Lee & Park, 1990). So, how is it possible that sound rhythms represent mental load variable? Possible explanation could come from listeners' instructions and nature of their task. They were instructed to listen to sound rhythms carefully and ac-

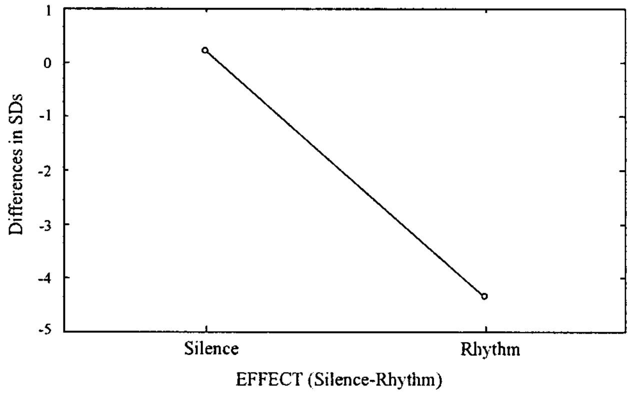

Figure 13. Average standard deviations for two levels of Silence-Rhythm Main Effect, $F(1,10) = 5.87; p < 0.036$.

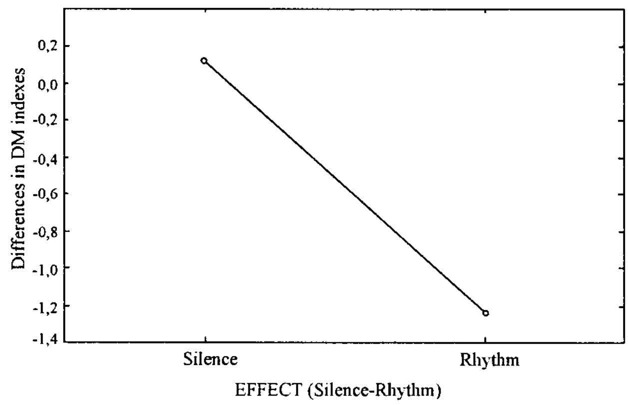

Figure 14. Average DM indexes for two levels of Silence-Rhythm Main Effect, $F(1,10) = 7,81; p<0,0190$.

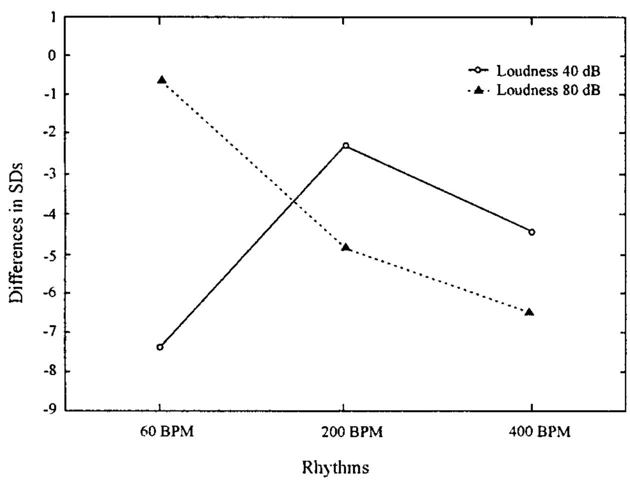

Figure 15. Average standard deviations for 2-way interaction (Intensity) X (Tempo), $F(2,20) = 4,63; p<0,022$.

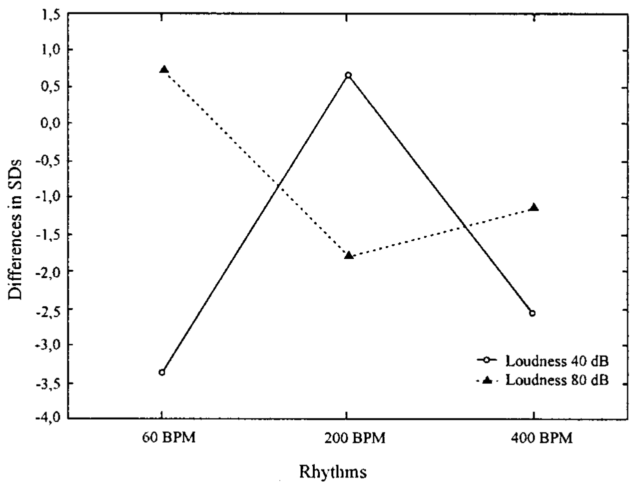

Figure 16. Average DM indexes for 2-way interaction (Intensity) X (Tempo), $F(2,20) = 4,34; p<0,0273$.

tively and this should mean that they have probably analyzed them. This rhythm analysis could have resulted with some mental or even emotional load, which, in turn, might have caused decrease in heart interbeat interval variability.

Two-way analysis of variance for factors Tempo and Intensity showed significant effects on both, standard deviations and DM indexes of heart interbeat intervals (Figures 15 and 16).

Interaction of those two factors (Tempo and Intensity of sound rhythm) was also significant. In both cases, more intensive rhythm effects were not significantly different from less intensive rhythm effects, *except* in case of the slowest and more intensive rhythm of 60 BMP and 80 dB, where the variability was significantly higher. Possible interpretations for this effect could be that cardiac rhythms were affected by close-frequency sound rhythms, supporting thus the initial hypothesis.

CONCLUSION

In conclusion, it can be said that effect of sound rhythms on cardiac rhythms was apparent, and it was more prominent for louder rhythms of 80 dB, while less loud rhythm effect was not clear. It seems that sufficiently loud sound rhythms, in situation where listener quietly listens to them, affect heart rate, by making it slower. However, this effect is contrary to the hypothesis on the excitement that music could produce and it looks more like relaxation effect.

It is also interesting that the described effect is the strongest when listening to slow rhythm of 60 BPM. That rhythm is close to heartbeat frequency and it is possible that the interference of two rhythms occurred. If this explanation holds, this would be similar to Manenica's (1972) results when externally imposed rhythm (of work) interfered with participant's cardiac rhythm.

All listening situations also resulted in decrease in variability of cardiac rhythm which is probably connected with mental load that occurred due to listeners' analysis of the sound rhythms. The interference that was mentioned earlier could have also contributed to the variability, which is supported by higher heartbeat variability found for the slowest rhythm. Further research with slower, louder and more complex sound rhythms should make these effects and mental load component clearer.

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