J. Human Ergol., **32**: 49-55, 2003

Communications

EFFECTS OF COMPLEX AURAL STIMULI ON MENTAL PERFORMANCE

Mohit Vij, Fereydoun Aghazadeh*, Thomas G. Ray, and Selen Hatipkarasulu

*Department of Industrial and Manufacturing Systems Engineering, Louisiana State University, Baton Rouge, LA 70803 U.S.A. / *Email: aghazadeh@lsu.edu*

The objective of this study is to investigate the effect of complex aural stimuli on mental performance. A series of experiments were designed to obtain data for two different analyses. The first analysis is a "Stimulus" versus "No-stimulus" comparison for each of the four dependent variables, i.e. quantitative ability, reasoning ability, spatial ability and memory of an individual, by comparing the control treatment with the rest of the treatments. The second set of analysis is a multi-variant analysis of variance for component level main effects and interactions. The two component factors are tempo of the complex aural stimuli and sound volume level, each administered at three discrete levels for all four dependent variables. Ten experiments were conducted on eleven subjects. It was found that complex aural stimuli influence the quantitative and spatial aspect of the mind, while the reasoning ability was unaffected by the stimuli. Although memory showed a trend to be worse with the presence of complex aural stimuli, the effect was statistically insignificant. Variation in tempo and sound volume level of an aural stimulus did not significantly affect the mental performance of an individual. The results of these experiments can be effectively used in designing work environments.

Key Words: mental peformance; aural stimuli; music; sound volume; tempo

INTRODUCTION

Music is an effective tool to influence the mind. Response to music is created internally (by human consciousness) and is reflected in a variety of behavioral, psychological, emotional, and physiological patterns. A particular note could possibly change a person's mood, preferences, and taste, and even put him to sleep (Izzard, 1977). This phenomenon has been exploited successfully in marketing, advertisements, training programs, production, and host of other applications.

In the field of production, several surveys and studies have been conducted to evaluate the change in employees' attitude, quantitative production output, and quality of goods produced and accident rates with the induction of music in the work environment. In most of these studies, music proved to be an effective medium to fulfill the demand for workers' happiness, while improving productivity (the two goals of management that are generally not in harmony). Smith (1947) conducted a study to determine the influence of an industrial music program in a plant of approximately 1,000 employees over a twelve-week period. Production under varying conditions of music increased 4% to 25%. Almost all (98 %) of the employees reported better job satisfaction with music playing during working hours. In another series of similar shop floor evaluations, there was a significant increase in productivity.

There exists substantial literature on the effects of music on various physiological and behavioral aspects of humans (Brickman, 1950; Clynes, 1978; Holdsworth, 1974; Lord, 1968; Sears, 1952; Sears, 1958; Stevens, 1971). However, the studies carried out so far, which address aural stimuli, are either concerned with the effects of noise or very loosely classified music, and further, there has been

Received for publication August 30, 2001

virtually no research related to evaluation of this effect in terms of measurable attributes of mental performance.

The objectives of the present study, therefore, were to test the hypothesis that administering a complex aural stimulus could affect the mental performance of an individual in quantitative ability, spatial ability, reasoning ability, and memory; to apply a scientific scheme for classification of complex aural stimulus based on its spectral pattern as a function of time; and to study the effects of tempo and sound volume level on the above-mentioned mental performance.

SUBJECTS AND METHODS

Aural Stimuli

Ten experiments were conducted which were divided into two major categories; the first in which mental performance test batteries were performed in the absence of any aural stimuli; the second under the influence of various combinations of complex aural stimulus with tempo and sound volume level set at three discrete levels. The former category serves as the control treatment in establishing a relationship between the conditions of presence or absence of complex aural stimuli. In the latter category, the stimulus tempo was administered at 0.42, 0.6, and 0.72 beats/second, and sound volume level was controlled at 56, 71, and 80 dBA, over a random sequence for each stimulus. The data obtained from these experiments provide a basis for the ‘sound’ versus ‘no sound’ comparison for each of the four dependent variables, and a multi-variant analysis of variance for component level main effects and interaction effects.

The no aural stimulus condition was a silent room with a background noise of 49 dB. The idea of factoring aural stimuli is a corollary of the modern stimulus perception theory that assumes that only the power spectrum of the stimulus is important for the perception of the information contained in the stimulus. The aural stimuli used for the experiments was an engineered piece of music extracted from a blend of Moderato by Meunet and Water Music by Haendel, with a basic pitch pattern that could be represented as a Fourier equation. This pattern was repeated in series to obtain a continuum over the complete length of each experiment.

Since the objective of the study related only to temporal variations of the spectral pitch pattern, a black box approach was adopted towards the spectral pattern itself. Varying the tempo brought about the variations in the stimulus. This is because the musical tone or melody perception is primarily a function of pitch contour and the precise intervals of pitch (tempo). In the present study, a specific contour was applied to all sets of experiment and thus was a constant. The only variation was in intervals, which resulted in a different musical tone. The different musical tones resulted in a different perception and thus the effects.

The loudness represented by sound volume level was varied for each set of temporal adjustment and studied for all the experiments. The loudness of the complex aural stimulus is defined as the attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from soft to loud (Harris, 1991). It was quantified vicariously by measuring the equipment volume of white noise generated at different logarithmic levels of sound energy. White noise was chosen because it represents a power spectrum density, essentially independent of frequency. Though this is not a true measure of the prevalent loudness as defined, but is significant so as to be able to quantify the “volumes” of the source of the aural stimulus through a standard procedure, easily reproducible.

Subjects and Mental Abilities

Eleven subjects, consisting of 8 males and 3 females, participated in all phases of this study. The age range of the subjects was between 22 and 35 years. Due to the multi-ethnic background of the limited number of subjects volunteering for the study, four primary intelligent quotient factors that best qualify as fluid abilities (Chattel, 1967; Chattel 1971) were chosen for the study. These are quantitative ability, spatial ability, inductive reasoning, and memory.

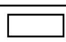
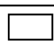
The reasons for choosing the above mentioned factors are because all the chosen factors are vital to a variety of job requirements, and also due to the cultural and educational diversity of the subject, it is deemed necessary to design the tests with a high g_f (fluid ability) and low g_c (crystallized ability) (Kline, 1993). In addition, experiments can be designed to quantitatively decipher the shift in each factor for a given test condition. No study to date has been conducted where any one or more of the factors have been treated as response variables to variations in engineered complex aural stimulus.

Test Batteries and Procedures

Before the beginning of each experimental session, the subjects were asked to relax for five minutes in silence. This was done to stabilize their cognitive state. Then, the first section of the test battery, the memory test, was administered. A list of fictitious names and addresses were spoken on the audio system twice, within an interval of 5 seconds. The name and address comprised of seven discrete words with no correlation with each other (memory chunks). These seven words served as seven chunks of information to be retained by the subjects till the end of the fourth battery, a total of 20 minutes. This was immediately followed by a reasoning ability, quantitative ability, and spatial ability test battery.

The tests consisted of 30 multiple-choice type numerical ability/quantitative ability problems, 25 reasoning ability problems of true or false and multiple choice types, and 25 multiple choice type spatial ability questions. Sample questions for different test batteries are represented in Table 1. The subjects were given a time window of six minutes for reasoning ability, three minutes for quantitative

Table 1. Sample questions for spatial, reasoning, and quantitative ability and memory tests.

Quantitative Ability Sample Questions						
1	8 + 12 * 2 - 16	(a) 25	(b) 16	(c) 23	(d) 22	(e) 24
2	12 * 13 - 15 + 1	(a) 144	(b) 143	(c) 141	(d) 142	(e) 140
Reasoning Ability Sample Questions						
Find out the missing number						
1	2 ; 10; …; 9 ; 4 ; 8	(a) 3	(b) 7	(c) 5	(d) 11	(e) 1
2	21 ; 12 ; 17 ; …; 23 ; 32	(a) 51	(b) 53	(c) 73	(d) 47	(e) 71
True or false						
1	(a) All students are not geniuses (b) Every student is a genius	T	F	U		
Fill in the blanks						
1	aba__bca__ac__cab__cbc	(a) bbbb	(b) ccba	(c) cbba	(d) caac	(e) cbbb
2	a__bbaa__baa__baab__aab	(a) abab	(b) baba	(c) abbb	(d) bbaa	(e) aaab
Find out the right number / letter						
1	7 5 8 8 8 8 6 0 ?	(a) 1	(b) 2	(c) 3	(d) 4	(e) 5
Spatial Ability Sample Questions						
This test consisted of matching parts and figures, box unfolding, hidden figures, cube counting, and visual-motor coordination tests.						
1		A. 	B. 	C. 	D. 	E. 
Memory Sample Questions						
1	Darryl Madinger 0386 Industrialway Rochester NewHampshire 30012					

ability, and seven minutes for the spatial ability tests, respectively. Subjects could do as many problems as they were able to do in the allotted time window. Each test battery was followed by another test battery in random order. All the test batteries were carried on the same lines. A rest interval of two minutes was included at the end of each battery. Subjects could keep sitting or relax, but were not allowed to talk or leave the experimentation room during the rest interval. After the rest interval of the third battery, each subject was asked to write whatever he/she was able to recollect of the names and the addresses. A thirty second period was given for this task.

Each experimental session lasted twenty-nine minutes and was recessed with duration not less than two days until the next session. This was to offset any residual effects of the control variables from the previous experiment.

Experimental Design and Statistical Analysis

The experimental design used in the study is a factorial design with two repeated factors, the (A x B x S) design. The experiment consisted of within subjects factors i.e., tempo of the complex aural stimuli and sound volume level. Each of the factors has three levels thus making it a 3 x 3 factorial experiment. There are eleven independent sample replicates, corresponding to the number of subjects for each of the 3 x 3 factor level combinations. Since there are four response variables, the strategy outlined by the Hummel and Sligo (1971) was used in this study. They demonstrate the routine use of ANOVA (Analysis of Variance) for each dependent variable, following a significant overall, multi-variant analysis of variance (MANOVA), which results in probability values that are closer to the desired levels. The present study uses Wilk's Lambda criteria because it has maximum sensitivity when two or more dimensions are contained in the set of dependent variables.

The comparison of the mental performance of the subjects in the absence and the presence of complex aural stimuli was carried out using contrast giving a balancing weight to the controls, so that the linear function of the treatment means was equal to zero. Essentially, the experiments were treated as a single factor design in this case. After a lack of interaction effect was established between the independent factors in the case of mental performances, Dunnett's test was used for specific comparison of the control treatment with individual treatments. This exercise was implemented in order to analyze the effect of individual factor of complex aural stimuli versus the no sound condition.

RESULTS AND DISCUSSION

Table 2 summarizes the scores for each test for three different tempos and sound volume levels. A single factor (listening condition) analysis of variance (ANOVA) was performed on the scores of each of the dependent variables of the test battery scores. The results of ANOVA are shown in Table 3, from which the following aspects were revealed.

Effects of Presence/Absence of Aural Stimuli on the Mental Abilities

Quantitative ability: The subjects performed better on the quantitative ability tests while listening to the engineered complex aural stimuli than in silence. The mean score was 12.82 (SD ± 2.09) for the stimuli and 10.27 (SD ± 5.05) for the control. Dunnett's test reveals a significant difference between the controlled treatments and those with the tempos and sound levels of 0.72 and 80, 0.72 and 56, 0.6 and 80, and 0.42 and 71, respectively.

Reasoning ability: The results do not reveal a significant improvement or decline in the performance of the subjects on the reasoning ability tests while listening to the engineered complex aural stimuli. The mean score for the treatment condition is 9.76 (SD ± 1.28) and that for control is 10.55 (SD ± 1.28), a difference of 0.79 (7.49%), which is insignificant due to large standard deviation in both data sets.

Spatial ability: The subjects performed better on the spatial ability tests while listening to the engineered complex aural stimuli than in silence. The mean score for the treatment condition is 17.82

Table 2. The scores for each test for three different tempos and sound volume levels (SVL).

Tempo	SVL	Quantitative ability Mean ± SD	Reasoning ability Mean ± SD	Spatial ability Mean ± SD	Memory Mean ± SD
0.42	80	12.09 ± 5.15	9.18 ± 1.72	17.27 ± 5.44	7.36 ± 2.25
	71	14.00 ± 5.92	11.45 ± 1.92	22.27 ± 5.42	7.36 ± 2.25
	56	9.36 ± 6.47	8.45 ± 1.75	13.27 ± 2.45	7.27 ± 1.79
0.60	80	14.45 ± 6.47	9.64 ± 2.80	21.27 ± 7.52	7.91 ± 2.47
	71	10.91 ± 4.30	9.00 ± 2.53	15.27 ± 4.90	6.82 ± 2.40
	56	11.64 ± 4.41	9.27 ± 2.05	16.91 ± 4.44	7.18 ± 1.83
0.72	80	15.91 ± 6.30	9.18 ± 3.16	20.00 ± 5.73	7.82 ± 2.23
	71	12.27 ± 6.23	9.27 ± 2.41	14.36 ± 2.84	7.64 ± 2.94
	56	14.73 ± 6.10	12.36 ± 2.11	19.73 ± 5.97	7.73 ± 1.62
Control		10.27 ± 5.05	10.55 ± 1.28	13.73 ± 4.25	8.73 ± 1.56

Table 3. The summarized results of ANOVA for the effects of tempos and sound volume levels.

Tests of Hypothesis		Dependent Variable							
		Quantitative Ability		Reasoning Ability		Spatial Ability		Memory	
Test	Error Term	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
Tempo	Subject * Tempo	6.44	< .0069	1.41	< .2677	0.09	< .9106	0.88	< .4308
SVL	Subject * SVL	4.67	< .0216	1.15	< .3355	3.05	< .0700	0.48	< .6241
Tempo * SVL	Subject * Tempo * SVL	4.91	< .0026	7.25	< .0002	10.35	< .0001	0.30	< .8758

(SD ± 3.17) and that for control is 13.73 (SD ± 4.25), a difference of 4.09 (an increase of 29.8%). Dunnett's test reveals a significant difference between the control treatments and those with tempos and sound volume levels of 0.42 and 71, 0.6 and 80, 0.72 and 80, and 0.72 and 56, respectively.

Memory: The subjects appeared to perform worse on the memory section of the tests while listening to the engineered complex aural stimuli than in silence. The mean score for the treatment condition is 7.45 (SD ± 0.35), and that for control is 8.73 (SD ± 1.56), a difference of 1.28 (a decrease of 14.66%). Dunnett's test reveals a lower score in all the treatments but none of them is significant.

Effects of Changes in Tempo/Sound Volume on the Mental Abilities

The second objective of the study was to investigate if a relationship exists between the change of tempo and sound volume level and the effect indicators of mental performance. The factorial effects on the dependent variables are summarized as follows.

Interaction effects: The scores for quantitative ability, reasoning ability, and spatial ability in the factorial design showed a significant interaction among the factors. This means that effects of one independent variable on the ability scores change at different levels of the second independent variable, and so the conclusion based on main effects alone does not fully describe the data. In the case of memory tests, there was a lack of significant interaction between both the factors.

Main effects: With respect to the effects of difference in tempo (0.42, 0.6, 0.72 beats/second) on the mental abilities, the test of hypothesis using ANOVA did not give a significant difference in the values of reasoning ability, spatial ability and memory scores of the subjects. A post hoc analysis by both LSD (least square difference) and Tukey's test of comparison of means showed a lack of significant difference in the scores for the subjects at all three levels of tempo. In the case of quantitative ability, however, the test of hypothesis gave a significant difference in the values of the scores. Post hoc analysis of comparison of means by the two tests showed a significantly higher value of quantitative score for the subjects at higher tempo (0.72 beats/second).

The second factor, difference in the sound volume level (56, 71, and 80 dBA), did not yield significant effects on the reasoning ability, spatial ability and memory of the subjects as a result of the hypothesis testing by using ANOVA. The lack of significance was confirmed with the results of post hoc analysis. In the case of quantitative ability, however, the test of hypothesis gave a significant difference in the values of scores. Post hoc analysis showed a grouping of 80 dBA and 71 dBA, and 71 dBA and 56 dBA. A significantly higher value of quantitative ability score was seen at higher volume level (80 dBA).

Summary of Findings and Their Significances

The above findings may be summarized as follows: The complex aural stimuli influence the quantitative and spatial abilities, while the reasoning ability is unaffected by the influence of these stimuli. The memory seems to have a trend to be worse in the presence of the stimuli. No general conclusion can be derived about the effects of factor level variables, i.e., tempo and sound level, on the mental abilities of an individual, in consideration of significant interactions between the variables.

It has been reported by some researchers that background noise deteriorates the cognitive performance. Furnham and Strbac (2002) investigated the effects of noise/music on a reading comprehension task, a prose recall task, and a mental arithmetic task, and found that performance of the individuals who participated in the study was worse in the presence of music and noise than silence. As mentioned before, however, studies which address aural stimuli are concerned with the effects of noise or very loosely classified music, and there have been few researches related to evaluation of the effects of music on measurable attributes of mental performance. The present study has investigated this aspect of mental performance.

The results shown above would be very useful in design of work environments, for a given mental function. For example, playing the right kind of music in a typical software development environment would stimulate the analytical mind of the programmers. Another application domain could be a complex monitoring and control unit, typical to power plants, refineries etc. Our findings can provide a better insight into the possibility of engineering and administrating specific auditory stimulus to improve the complex information processing function required in the job.

REFERENCES

Brickman, HR (1950) Psychiatric implications of functional music for education. *Music Educators J.*, **36**: 29-30.

Chattell, RB (1967) The theory of Fluid and Crystallized Intelligence. *British J. Educ. Psychol.*, **37**: 209-224.

Chattell, RB (1971) Abilities: Their Structure, Growth, and Action. Houghton Mifflin,Boston.

Clynes, M (1978) Sentics: The Touch of Emotions. Anchor Books, New York.

Furnham, A and Strbac, L (2002) Music is as distracting as noise: The differential distraction of background music and noise on the cognitive test performance of introverts and extraverts. *Ergonomics*, **45**: 203-217.

Harris, CM (1991) Handbook of Acoustical Measurements and Noise Control. McGraw Hill, New York.

Holdsworth, E (1974) Neuromuscular activity and covert musical psychomotor behavior: An electromyographic study. *Un-*

published doctoral dissertation, University of Kansas. Mentioned in: Handbook of Music Psychology, ed. by Hodges, D, National Association of Music Therapy, Lawrence, Kansas, 1980.

Hummel, TJ and Sligo, J (1971) An empirical comparison of univariate and multivariate analysis of variance procedures. *Psychol. Bull.*, **76**: 49-57.

Izzard, CE (1977) Human Emotions. Plenum Press, New York.

Kline, P (1993) The Handbook of Psychological Testing. Routledge, New York.

Lord, W (1968) The effects of music on muscle activity during exercise as measured by heart rate. *Unpublished paper, University of Kansas*. Mentioned in: Handbook of Music Psychology, ed. by Hodges, D, National Association of Music Therapy, Lawrence, Kansas, 1980.

Sears, WW (1952) Postural responses to recorded music. *In*: Music Therapy, ed. by Gilliland, EG, Allen Press, Lawrence, Kansas, pp.197-198.

Sears, WW (1958) The effect of music on muscle tonus. *In*: Music Therapy, ed. by Gaston, ET, Allen Press, Lawrence, Kansas: pp.199-205.

Smith, HC (1947) Music in relation to employee attitudes, piecework production and industrial accidents. *Applied Psychology Monographs of the American Psychological Association.*

Stevens, EA (1971) Some effects of tempo changes on stereotyped rocking movements. *Am. J. Mental Deficiency*, **76**: 76-81.