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Effects of music and white noise on working memory performance in monkeys

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It has been suggested that Mozart's music may have beneficial effects on the performance of cognitive tasks in humans. In the present study the effects of Mozart's piano music, white noise, simple rhythm and silence were studied on the performance of a delayed response (DR) task in monkeys. The acoustic treatments were given for 15 min, either before or during DR testing. The acoustic treatments did not affect DR performance when given before testing. However, Mozart's piano music played during DR testing caused a significant deterioration in the performance of the monkeys, whereas white noise improved it. It is suggested that Mozart's music serves as distractive stimulation during DR performance thus affecting working-memory-related neuronal processing and performance. White background noise, on the other hand, may improve DR performance by protecting against environmental distraction during testing.

Key words: Delayed response; Distraction; Music; Prefrontal cortex; Working memory

Introduction

Attention has recently been drawn to the possibly positive effects of listening to Mozart or other classical music on cognitive performance.[1,2] Students listening to Mozart's piano music for 10 min before testing performed better in IQ spatial reasoning tasks than when they had listened to a relaxation tape or remained in conditions of silence.[1] Repetitive music had no positive effect on spatial reasoning or short-term memory performance measured with 16 short-term memory items. While the effect of Mozart's classical music on intellectual performance of the students was consistent in the above studies, the neurophysiological basis of this effect has remained obscure.

Monkeys have been used as experimental animals in numerous studies concerning neuronal processing of working memory in the prefrontal cortex.[3–5] Lesion studies in monkeys have shown that the prefrontal cortex is part of the neuronal network processing spatial working memory.[6–8] Furthermore, neurons in and around the principal sulcus in the dorsolateral prefrontal cortex have been shown to change their firing rate during the cue, delay, and response periods of such working memory tasks as the delayed alternation and delayed response (DR) tasks.[9–13] These tasks require that the subject holds in mind new information for a short period of time (usually a few seconds) in order to respond correctly. Many neurons in the prefrontal cortex code the spatial location of the cue stimulus in DR tasks and express spatially selective delay-related changes in their firing rate.[4,5] It has, therefore, been suggested that such neurons represent the neuronal substrate for short-term memory.

In several experiments the effects of various drugs on working memory performance have also been studied in monkeys trained to perform DR tasks.[14–16] In our laboratory we recently completed a project in which the effects of an alpha-2 receptor agonist medetomidine and its antagonist, atipamezole, were studied on monkeys performing a DR task.[16]

In the present work we revisited the question about the possible effects of classical music on cognitive performance. The study was conducted in monkeys trained to perform a DR task. Since monkeys are naive listeners to classical or any other type of music, they have no predilections or expectations about possible effects of different kinds of music on their cognitive performance. In this study the monkeys performed a manual version of a DR task while Mozart's piano music, silence, simple rhythm and white noise were played either before or during the task performance. The rationale of the study was that if the earlier reported improvement in the performance of students in cognitive tasks[1,2] was due to some unknown positive effect of Mozart's music on the neuronal processing related to working memory performance, this effect might become evident also in monkeys. The paradigm was adapted from drug studies,[14–16] the only difference being that, instead of the effects of drugs, we studied the effects of different acoustic treatments on working memory performance.

Materials and Methods

Five stump-tailed macaques (*Macaca arctoides*; two females and three males, age 18.5–29 (mean 21.8) years) were trained to perform a DR task according to a method described in detail earlier.[16] The monkeys were the same as those in our earlier study in which the effects of α2-adrenergic drugs on working memory performance were studied. The monkeys had therefore been extensively trained to master the DR task. During the training and testing the monkeys were housed individually in their standard home cages with one or two other monkeys of the colony. The animals had free access to water and the main portion of the daily food was given after the testing session. The study had been approved of by the Animal Ethics committee of the Institute of Biomedicine, University of Helsinki.

The monkeys were trained to perform a spatial DR task with five different delays. The testing apparatus which was attached to the cage had two horizontally located foodwells at a distance of 15 cm from each other. The monkey watched through a transparent screen when a raisin was hidden in one of the two foodwells (Fig. 1). The foodwells were covered with identical wooden lids and an opaque screen was lowered for the delay period at the end of which both the opaque and transparent screens were raised. Through an opening in the cage the monkey reached the foodwells with its hand. If the choice was correct the monkey found a raisin under the cover as a reward.

Training started with 0 s delays (the shortest delay needed to lower and raise the screens). The daily training session consisted of 30 trials. The training continued until the monkeys learned to respond correctly to 90% of the trials. The delay was then gradually lengthened, but the same delay was used in all 30 daily trials, until the performance of the monkeys dropped near chance level. Varying delays between these two limits were then introduced. The other three intermediate delays were adjusted so that the performance of the monkeys was about 65% correct choices of the 30 trials.

In the first experimental condition the acoustic treatments were silence or white noise, simple rhythm consisting of repetitions of a 5 s epoch, or Mozart's piano music (Piano Concerto No. 21 in C) played for 15 min before the testing. The experimenter was unaware of the type of acoustic treatment that had been given before the testing. In the second experimental condition they were played throughout the testing. Only one acoustic treatment was given in a daily session. The different acoustic treatments of one experimental condition (either before or during testing) were given on consecutive days. The mean background noise level in the 'silent' monkey room was 41 dB (38.4–43.4 dB) in 10 measurements (Precision Sound Level Meter Type 2203, Brüel & Kjaer). The mean background noise level during white noise was 80 dB (79.5–79.7 dB), during simple rhythm 74 dB (73.3–74.5 dB) and during Mozart 80 dB (76.3–85.2 dB).

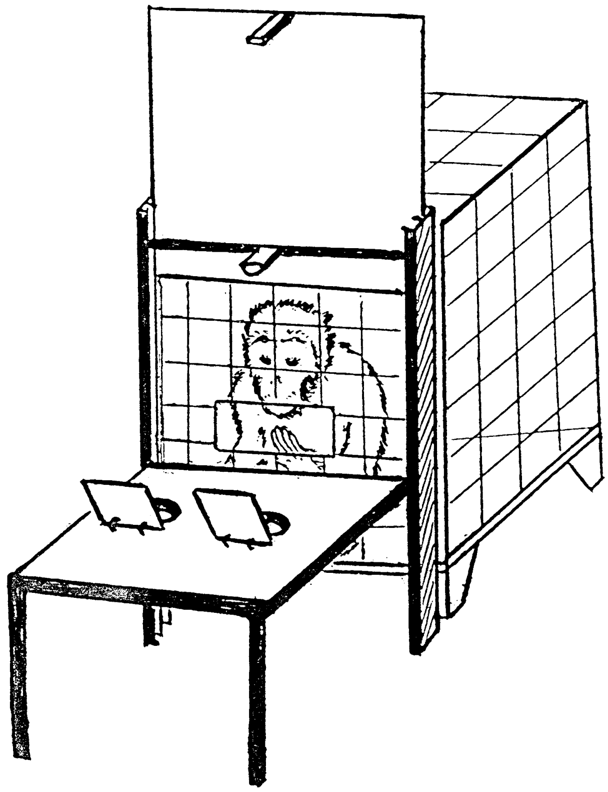

FIG. 1. The testing cage and the test board. The opaque screen is raised so that the monkey can see where the reward is hidden. A transparent screen hinders the monkey from reaching the wells.

The DR task performance after/during white noise, simple rhythm or Mozart's music (treatment) was compared with performance after/during silence (control). The number of trials correct on silence was subtracted from the number of trials correct on treatment. The difference score was multiplied by 3.3, as each trial constituted 3.3% of the total number of trials (30 trials/session). The data were analysed statistically using one-way analysis of variance with repeated measures (1-ANOVA-R) and a *post hoc* analysis using the paired *t*-test.

Results

In the first experimental condition, the performance on the treatment given before the DR task did not differ from that on silence ($F(2,4) = 0.024$, $p = 0.977$, Fig. 2A). Thus, the acoustic treatment presented before the task performance neither

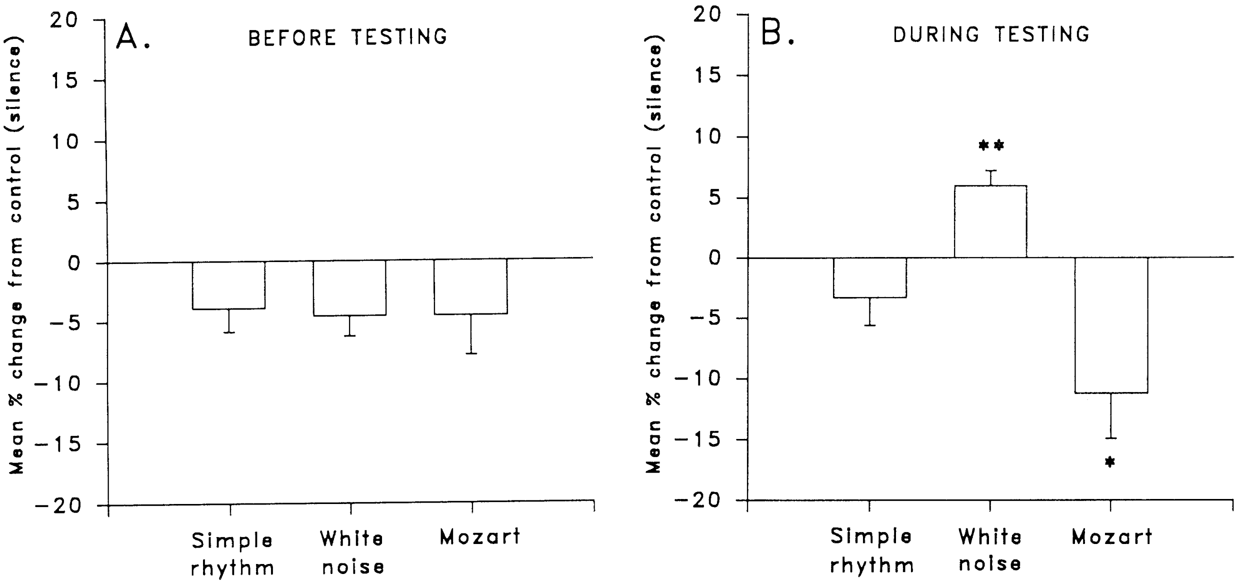

FIG. 2. (**A**) White noise or music played before testing in the DR task had no significant effect on the task performance compared with the control condition (silence). (**B**) The DR task performance improved significantly when white noise was played during testing but was impaired when Mozart was played. The black bars indicate the mean percentage change from silence in five monkeys. Vertical lines = s.e.m. $*p < 0.05$, $**p < 0.01$.

improved nor impaired the task performance. In the second experimental condition, in which music or white noise was played during the DR testing, the treatment had a statistically significant effect on the performance of the monkeys compared with their performance during silence (1-ANOVA-R: $F(2,4) = 10.32$, $p = 0.0061$). Their performance improved significantly during white noise ($t(4) = 4.81$, $p = 0.0086$, paired *t*-test) and was impaired during Mozart's piano music ($t(4) = 3.03$, $p = 0.039$, paired *t*-test, Fig. 2B). In the second experimental condition, during silence, the monkeys made significantly more mistakes at the three longest delays (III-V) compared with the shortest delay (I) (Fig. 3, 1-ANOVA-R: $F(4,4) = 6.60$, $p < 0.005$; I *vs* III $t(4) = 4.30$, $p < 0.01$, I *vs* IV $t(4) = 4.30$, $p < 0.01$, I *vs* V $t(4) = 3.64$, $p < 0.01$). White noise particularly improved performance, although not statistically significantly, on the longer delays resulting in a relatively even distribution of mistakes over the different delays. In other words, there were no statistically significant differences between the numbers of mistakes at different delays in the task performance during white noise. Mozart's music, on the other hand, increased the number of mistakes over all other delays except the shortest delay, resulting in a statistically significant difference in the numbers of mistakes between the shortest delay and the other four delays (Fig. 3, 1-ANOVA-R: $F(4,4) = 9.50$, $p < 0.005$; I *vs* II $t(4) = 4.55$, $p < 0.01$, I *vs* III $t(4) = 4.55$, $p < 0.01$, I *vs* IV $t(4) = 3.15$, $p < 0.05$, I *vs* V $t(4)=5.61$, $p > 0.001$).

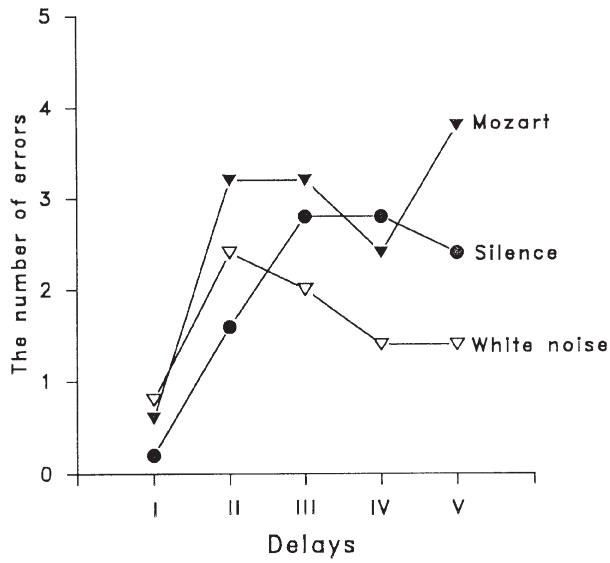

FIG. 3. The mean number of errors for each delay during silence and during the two acoustic treatments which significantly affected the DR performance.

Discussion

Music or white noise played before the DR task had no effect on the working memory performance. There was thus no positive 'Mozart effect' on short-term memory performance in monkeys as described on spatial-temporal reasoning in students.[1,2]

In the second experimental condition auditory stimulation was present throughout the testing. Interestingly, Mozart played during the DR task deteriorated the performance of the monkeys whereas white background noise improved it. Rather than claiming that monkeys do not understand Mozart's music we suggest that neuronal processing related to working memory does not benefit from complex and therefore potentially disruptive auditory stimulation. It has been shown earlier that distraction during the delay period of the DR task changes the neuronal firing rate of delay-related neurons[12] and also disrupts performance, leading to erroneous choices.[12,17] Since Mozart's piano music is far from being monotonous, it may have attracted the monkeys' interest not only during the delay but at the varying phases of the task thus disrupting the performance. On the other hand, the beneficial effect of white noise on working memory performance may be due to its protecting effect on working memory processing by masking disruptive acoustic sounds. In the present set-up, as in our previous study, the testing room was not acoustically shielded, although relatively quiet. Some noise was caused by the monkey's own movements in the cage and by the researcher who manually raised and lowered the screens. Such experimental conditions are vulnerable to distraction and, as has been discussed earlier, may affect the level of performance of the monkeys.[15] Thus it is plausible that under these circumstances white background noise was beneficial to the DR performance.

Conclusion

Recently it was reported that Mozart's music improves the performance of students in cognitive tasks, suggesting that classical music may have a positive effect on the function of neuronal circuitries engaged in these tasks. In the present work we addressed this question in monkeys trained to perform a delayed response task. The rationale was that if classical music tunes neurons in a way beneficial for cognitive performance, this effect would become evident also in monkeys who are naive listeners of music and do not have any predilections of its effects. Mozart's music, when played before the testing, had no positive effect on the task performance. During the task it impaired the performance whereas white noise improved it. It is suggested that complex music may serve as distraction during tasks requiring attentiveness. White noise, on the other hand, may protect from any distraction during testing and thus improve the performance.

References

1. Rauscher FH, Shaw GL and Ky KN. *Nature* **365**, 611 (1993).
2. Rauscher FH, Shaw GL and Ky KN. *Neurosci Lett* **185**, 44–47 (1995).
3. Funahashi S and Kubota K. *Neurosci Res* **21**, 1–11 (1994).
4. Fuster JM. *The Prefrontal Cortex. Anatomy, Physiology and Neurophysiology of the Frontal Lobe*. 2nd edn. New York: Raven Press, 1989.
5. Goldman-Rakic PS. Circuitry of primate prefrontal cortex and regulation of behavior by representational memory. In: Plum F and Mountcastle VB, eds. *Handbook of Physiology*. Vol. 5. Bethesda: American Physiological Society, 1987: 373–417.
6. Goldman PS and Rosvold HE. *Exp Neurol* **27**, 291–304 (1970).
7. Jacobsen CF. *Comp Psychol Monogr* **13**, 1–68 (1936).
8. Mishkin M and Pribram KH. *J Comp Physiol Psychol* **48**, 492–495 (1955).
9. Carlson S, Rämä P, Tanila H *et al. J Neurophysiol* **77**, 761–774 (1997).
10. Funahashi S, Bruce CJ and Goldman-Rakic PS. *J Neurophysiol* **61**, 331–349 (1989).
11. Fuster JM and Alexander GE. *Science* **173**, 652–654 (1971).
12. Fuster JM. *J Neurophysiol* **36**, 61–78 (1973).
13. Niki H. *Brain Res* **70**, 346–349 (1974).
14. Arnsten AFT and Goldman-Rakic PS. *Science* **230**, 1273–1276 (1985).
15. Bartus RT and Dean RL. *Neurobiol Aging* **9**, 409–411 (1988).
16. Rämä P, Linnankoski I, Tanila H *et al. Pharmacol Biochem Behav* **55**, 415–422 (1996).
17. Arnsten AFT and Contant TA. *Psychopharmacology* **108**, 159–169 (1992).

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