
Do Rats Show a Mozart Effect?

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The “Mozart effect” is an increase in spatial reasoning scores after listening to a Mozart piano sonata. Both the production and interpretation of the effect are controversial. Many studies have failed to replicate the original effect. Other studies have explained a Mozart effect as being caused by changes in arousal or differences in preferences of the listener. F. H. Rauscher, K. D. Robinson, and J. J. Jens (1998) reported that rats learned to complete a T-maze more quickly if they had been exposed in utero and reared hearing a Mozart piano sonata. They concluded that the result indicated a direct effect of the music on brain development and contradicted competing accounts of arousal or preference. This article is an analysis of the experiment by Rauscher et al. The in utero exposure would have been ineffective because rats are born deaf. A comparison of human and rat audiograms, in the context of the frequencies produced by a piano, suggests that adult rats are deaf to most notes in the sonata. The successful performance of the Mozart group may be explained by the incomplete use of random assignment of subjects to groups and by experimenter effects in the construction of groups. The results of Rauscher et al. (1998) do not provide strong support for the existence of the Mozart effect.

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THE original “Mozart effect” is an increase in spatial reasoning scores after listening to the first section of a Mozart piano sonata, the Sonata for Two Pianos in D Major, K. 448 (Rauscher, Shaw, & Ky, 1993, 1995). Rauscher et al. (1993, 1995) interpreted their results and concluded that hearing the music caused the improvement through direct neural priming of spatial reasoning areas in the brain. This interpretation was used as the basis for their strong advocacy of exposure to music in schools to improve mathematics scores (Rauscher, 1997, 1999a; Shaw, 2000).

Shaw (2001) has enlarged the domain of the Mozart effect to include reports that patients with Alzheimer’s disease/dementia show improved

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performance on a visual-spatial task after hearing the Mozart piano sonata (Johnson, Cotman, Tasaki, & Shaw, 1998; Johnson, Shaw, Vuong, Vuong, & Cotman, 2002) and that exposure to this piano sonata reduced seizure activity in epileptic patients, even when the person was in a coma and therefore unconscious (Hughes, Daaboul, Fino, & Shaw, 1998). Shaw includes in this “Mozart effect generalized” a study by Rauscher, Robinson, and Jens (1998) which reports that long-term exposure of rats to this Mozart piano sonata produced enhanced maze-learning. An analysis of the Rauscher et al. (1998) experiment is the subject of this article.

The existence of the original Mozart effect is a matter of great controversy. More laboratories have been unable to produce a Mozart effect (Bridgett & Cuevas, 2000; Carstens, Huskins, & Hounshell, 1995; Kenealy & Monsef, 1994; McCutcheon, 2000; McKelvie & Low, 2002; Newman, Rosenbach, Burns, Latimer, Matocha, & Vogt, 1995; Ong, Lu, & Smith, 2000; Steele, Bass, & Crook, 1999; Steele, Dalla Bella, et al., 1999; Stephenson, 2002; Stough, Kerkin, Bates, & Mangan, 1994; Weeks, 1996) than have been able to produce the effect (Nantais & Schellenberg, 1999; Rideout & Laubach, 1996). Even positive results have been interpreted as being explained by arousal or preference differences instead of musical priming of spatial reasoning areas of the brain (Chabris, 1999; Husain, Thompson, & Schellenberg, 2002; Nantais & Schellenberg, 1999; Steele, 2000; Steele, Ball, & Runk, 1997; Thompson, Schellenberg, & Husain, 2001).

Chabris (1999) conducted a meta-analysis of *published* studies and concluded that music enhanced spatial reasoning a trivial amount ($d = 0.14$ standard deviation [SD] units, the equivalent of 2.1 IQ points) when the control condition was silence. The effect size was increased ($d = 0.56$ SD units) when the control condition was auditory relaxation instructions. Because relaxation instructions are designed to reduce arousal, Chabris concluded that arousal differences explain cases in which a Mozart effect is found. Hetland (2000) published a meta-analysis that came to a different conclusion. Hetland concluded that the effect size was much larger ($d = 0.50$ SD units) for spatial task performance. What accounts for the discrepancy between the two reports? One important difference was that Hetland chose to include *unpublished* results. This choice produced the inclusion of several studies from a specific laboratory (Rauscher, Bowers, & Kohlbeck, 1999; Rauscher & Hayes, 1999; Rauscher & Ribar, 1999). However, Hetland’s meta-analysis found a “lab effect” also. Results from Rauscher’s lab showed significantly stronger Mozart-effect results relative to all other labs (Hetland, 2000, p. 134). Mean effect size from Rauscher’s lab was more than twice as large as results from other labs. Hetland suggested that this difference may be due to unidentified procedural differences. This produces a problem for evaluation of Hetland’s overall conclusion about the Mozart effect because it is difficult to evaluate procedural differences when the studies of interest are unpublished.

Rauscher and Shaw (1998) suggested that failures were due to inappropriate procedures or inappropriate spatial reasoning measures. However Steele, Bass, and Crook (1999) replicated the procedure of Rauscher et al. (1995) and were unable to produce a Mozart effect. Steele, Dalla Bella, Peretz, et al. (1999) were unable to produce a Mozart effect in three experiments that used the general procedures of both experiments by Rauscher et al. Rauscher (1999b) suggested these negative results were caused by procedural artifacts. Rauscher's main criticism was Steele et al.'s *use of random assignment* of subjects to experimental conditions. Rauscher et al. (1995) used results from a pretest to construct "equivalent groups" before the experimental session.

Rauscher (1999b) and Shaw (2000) have cited the experiment by Rauscher et al. (1998) as additional proof of the existence of the effect. Rauscher et al. (1998) reported the production of a Mozart effect in rats. The result was interpreted to indicate that the Mozart effect is a neurophysiological effect, not a cultural or arousal-preference effect, which "provides a window into higher brain function" (Shaw, 2000). This article analyzes that experiment to determine whether a Mozart effect was produced in rats.

The Rauscher et al. (1998) Experiment

Rauscher et al. (1998) bred rats in the presence of a repeating 8 min 24 s tape loop of either the first portion of the Mozart piano sonata (K. 448), an equivalent duration from Philip Glass's *Music With Changing Parts*, or white noise. The pregnant rats received continued exposure to their original sound condition (Mozart, Glass, or White Noise) for 12 h per day at an intensity of 65 to 70 dB throughout the gestation period. After birth, rat pups were exposed additionally to that sound condition for another 60 days, 12 h per day. After weaning, all animals were handled for 1 min daily to accustom them to human contact. Beginning on the 61st day, 90 rats (30 per sound-rearing condition, equal numbers of males and females) were trained on a six-unit T-maze. Each sound-condition group was further subdivided into three groups of 10, and each subgroup was trained in the maze in the presence of either the Mozart sonata, the Glass music, or white noise. Sound levels in the maze registered 65 to 70 dB. Testing was performed "blind" over the course of 5 days, three trials per day, with 10-min rest periods between trials. (The "blinding" procedure was not described.) Trials were videotaped. Dependent measures were working time in the maze and errors (blind-alley entrances).

Rauscher et al. (1998) reported that the Mozart-reared group performed significantly better at learning the maze. The Mozart group produced significantly fewer blind-alley entrances than the white-noise group on the

first day of training. The Mozart-reared rats learned over days to reach the reward more quickly than the Glass or White Noise groups. There was no effect of the specific music played during training inside the maze, and there was no significant interaction between music-rearing condition and music-in-the-maze condition. A Mozart-reared rat reared was not hampered by having Glass played in the maze, and a Glass-reared rat was not helped by having Mozart played in the maze.

Rauscher et al. (1998) conducted a second experiment to test whether the rearing-condition difference could be due to a decrease in performance in the Glass and White Noise groups. Two groups ($N = 12$ and $N = 8$) were exposed to silence in utero and 60 days postpartum and then tested in the maze during exposure to either silence or white noise. A third group ($N = 8$) was exposed to white noise originally and then tested in silence. Rauscher et al. found no significant effect of rearing condition or significant interaction between rearing condition and sound condition in the maze. Learning performance was unaffected by switches to a new sound stimulus in the maze.

Rauscher (1999b) and Shaw (2000, 2001) did not explain why rats would be expected to show a Mozart effect and cited no work demonstrating that listening to classical music would improve learning in rats. A review of the literature indicated that only two studies had examined the specific effect of classical music on rats before Rauscher et al. (1998). The results of both studies raised questions about what rats heard of the music.

What Is the Effect of Classical Music on Rats?

Cross, Halcomb, and Matter (1967) investigated imprinting to sound by having groups of rats reared listening to music either by Mozart or by Schoenberg and asked whether rearing condition would predict sound preference in a choice task. The Mozart group did show a preference for Mozart over Schoenberg but the Schoenberg group did not prefer Schoenberg. Cross et al. explained the lack of preference of the Schoenberg group as possibly due to differences in vividness, intensity, or attention-getting characteristics between the two sets of music. In other words, Cross et al. expressed concern that the Schoenberg rats had not heard their music well enough to produce an imprinting effect.

Bates and Horvath (1971) investigated whether exposure to classical music would improve discrimination learning in rats. Rats were trained to solve a visual discrimination task in the presence of either a Mozart symphony, a monotonic amelodic version of that Mozart symphony (which preserved only the rhythm component), a Schoenberg chamber symphony, a monotonic amelodic version of the Schoenberg selection, white noise, or quiet. Bates and Horvath found that rats trained in the presence of Mozart

produced more correct responses than rats exposed to Schoenberg but there were no differences in learning rate between rats that heard the original music and rats that heard the altered music, for both the Mozart and Schoenberg group. In other words, greatly altering the music did not affect the rats' rate of learning. Finally, the best discrimination performance was produced by the rats in the quiet condition. The lack of effect of altering the music suggests that rats may not hear all aspects of the music.

What Is the Effect on a Rat of in Utero Exposure to Music?

Rauscher et al. (1998) argued for the need to establish an animal model to investigate the physiology of the Mozart effect but did not explain why rats were chosen as the appropriate model. The use of animal models has a long and honorable history. However, one must always be concerned that one has made the appropriate translation from one domain to another. Rauscher et al. (1998) treated rats as if they were humans by exposing the rats to the music in utero. The human infant hears at birth, and there is evidence that the fetus responds to vibration by 26 weeks (Gagnon, Hunse, Carmichael, Fellows, & Patrick, 1987). Some mammals hear at birth, including goat and guinea-pig, but many mammals do not, including ferrets, gerbils, and rats (Sohmer & Freeman, 1995). Rats are deaf to air-borne sounds until about 11 days after birth. Geal-Dor, Freeman, Li, and Sohmer (1993) exposed young rats from birth through 10 days old to 135 dB SPL click stimuli without provoking a response in auditory brainstem neurons. Deafness is due, in part, to lack of conduction of sound because the bones of the middle ear have not ossified. In addition, the newborn rat shows sensorineural deafness. The earliest auditory brainstem response to direct 80-dB vibration of the skull does not appear until a week after birth (Geal-Dor et al., 1993) and a cochlear microphonic response does not appear for another 2 days (Uziel, Romand, & Marot, 1981).

What Sound Frequencies Do Humans and Rats Hear?

The approach of Rauscher et al. was to expose rats to music, using the same music selections at the same sound intensities as were used in their human-subject experiments. This procedure was based on the assumption that musical stimuli appropriate for human hearing would suffice for rats. The available evidence from comparative psychophysics indicates that the assumption was wrong.

Figure 1 shows a typical human audiogram (Jackson, Heffner, & Heffner, 1999). The figure shows how intense a sound must be to be above absolute threshold for different frequencies. A value of 0 dB SPL is the conventional

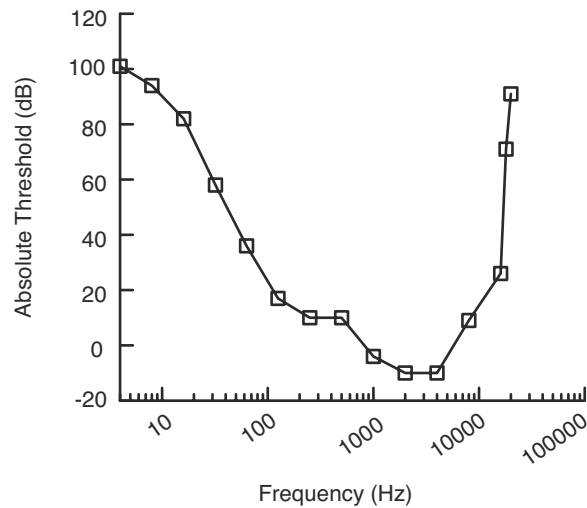


Fig. 1. Human audiogram illustrating the relationship of absolute threshold to stimulus frequency. Stimulus intensity was measured in decibels (dB SPL), and frequency was measured in Hertz. Note that frequency is reported on a log scale. Greater sensitivity is indicated by lower threshold values. The results are from Jackson et al. (1999).

absolute threshold for human hearing. Each increment of 20 dB indicates that the physical intensity of the stimulus has been increased by a factor of 10 (Matlin & Foley, 1997, p. 281). The change from 0 to 100 dB represents a change by a factor of 100,000 in the intensity of the stimulus. Although it is true that the typical human hearing range is from 20 Hz to 20,000 Hz, it is clear that we are not sensitive equally to sounds across that range. The figure illustrates that human hearing may be broken roughly into three bands: below 100 Hz, 100 to 8000 Hz, and above 8000 Hz. Human hearing is sensitized to detect and discriminate among sounds in the middle band, the location of speech frequencies. The lower and higher frequency bands are used primarily for sound localization (Coren, Ward, & Enns, 1999; Stevens & Newman, 1934, 1936).

Table 1 shows the fundamental frequencies associated with each note on the piano keyboard (Reblitz, 1976). The table shows notes organized in columns by octaves and in rows by note names. “C₄” designates the “C” note in the fourth octave and is referred to as “middle C.” The range of frequencies across the entire keyboard is from 27.5 Hz to 4186 Hz, and the range for the two middle octaves is from 220 Hz (A₄) to 831 Hz (G₅). Both sets of ranges indicate that piano note frequencies are located where our hearing is most sensitive. This is not surprising because humans developed the piano to affect human ears.

Figure 2 shows the addition of a typical audiogram for *Rattus* into Figure 1 (Heffner, Heffner, Contos, & Ott, 1994; also see additional audio-

TABLE 1
Theoretical Fundamental Frequencies for the 88 Piano Notes

Note	Octaves							
	1	2	3	4	5	6	7	8
G#	51.913	103.826	207.652	415.305	830.609	1661.219	3322.437	
G	48.999	97.999	195.998	391.995	783.991	1567.982	3135.437	
F#	46.249	92.499	184.997	369.994	739.989	1479.978	2959.955	
F	43.654	87.307	174.617	349.228	698.456	1396.913	2793.826	
E	41.203	82.407	164.814	329.629	659.255	1318.520	2637.020	
D#	38.891	77.782	155.563	311.127	622.254	1244.598	2489.016	
D	36.708	73.416	146.832	293.665	587.330	1174.659	2439.318	
C#	34.648	69.296	138.591	277.183	554.365	1108.731	2217.461	
C	32.703	65.406	130.813	261.626	523.251	1046.502	2093.004	4186.009
B	30.868	61.735	123.471	246.942	493.883	987.767	1975.533	3951.066
A#	29.135	58.270	116.541	233.082	466.164	932.328	1864.655	3729.310
A	27.500	55.000	110.000	220.000	440.000	880.000	1760.000	3520.000

grams in Fay, 1988). The figure indicates that the audiogram for the rat is shifted toward much higher frequencies, with lowest thresholds at 8,000 Hz and 32,000 Hz. One reason for the shift in frequency sensitivity is sound localization (Heffner & Heffner, 1998). The pinna (outer ear) and the head alter the characteristics of the sound signal to produce sound-level differences between the ears and these intensity differences are then used in sound localization. There is an inverse relationship between the size of the head

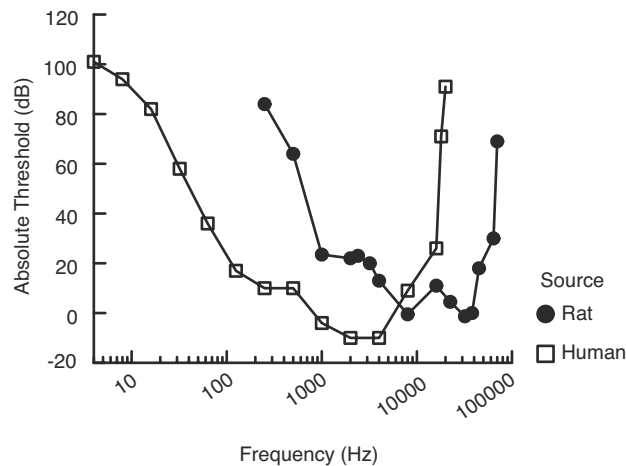


Fig. 2. Relationship between human audiogram and rat audiogram. Stimulus intensity was measured in decibels (dB SPL), and frequency was measured in Hertz and is reported on a log scale. Greater sensitivity is indicated by lower threshold values. The human results (unfilled squares) are from Jackson et al. (1999) and the rat results (filled circles) are from Heffner et al. (1994).

cum pinna and the sound frequencies most affected. Smaller heads work best with the attenuation of higher frequencies. A shift to higher-frequency sensitivity permits rats to use differences between the ears to localize sounds successfully.

What Notes Would Be Heard in the Mozart Piano Sonata?

Figure 3 shows the addition of dashed lines to indicate the location of 65 and 70 dB, the sound-intensity range used by Rauscher et al. (1998). Frequency points above the lines indicate frequency values that would require a higher intensity than was presented in the Rauscher et al. experiment to be above absolute threshold. These frequencies would not be heard at the sound intensity used in the Rauscher et al. experiment. The dashed-lines intersect the rat audiogram at approximately 500 Hz, and suggest that sounds below 500 Hz were below absolute threshold for the rats in this experiment. The values in Table 1 indicate that 500 Hz corresponds to a point between B₅ and C₅ on the keyboard. The location of this value suggests that piano notes from the lower four octaves would be below abso-

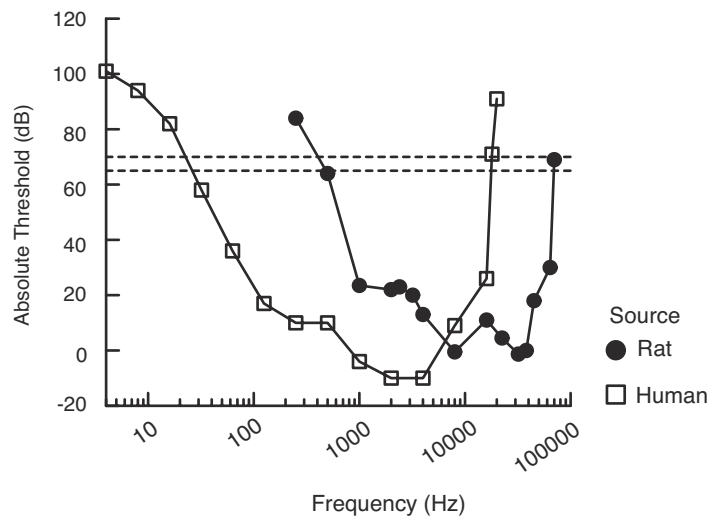


Fig. 3. Sound intensity cutoff lines applied to audiograms. The dashed lines indicate the range of amplitude of stimuli (from 65 to 70 dB) used by Rauscher et al. (1998). In order to be above absolute threshold, frequency values located above the dashed line would require higher amplitudes than were provided in the experiment by Rauscher et al.. The dashed lines intersect the rat audiogram at approximately 500 Hz, suggesting that frequencies below 500 Hz were inaudible.

lute threshold for subjects in the Rauscher et al. (1998) experiment. This is a conservative estimate because the presence of other sounds, for example, the sound of a ventilation fan, would produce masking noises that would increase the absolute threshold of a note further.

Hypothesizing that only C_5 and notes of higher frequency were above threshold would suggest that rats could hear only 37/88 (42%) of the available piano notes. Therefore it is important to know which notes occurred in the Mozart piano sonata because rats would not have heard the lower-frequency notes. A count of the amount of each note was obtained from a standard musical score (Hughes, 1926) for the first movement of the K. 448 sonata. Figure 4 shows the percentage of notes in the score, collapsed into octaves. The point for Octave 1 indicates the proportion of notes from that octave, and was computed from the sum of all occurrences of notes from A_1 to $G\#_1$ divided by the total number of notes. Other octave percentages were calculated in a similar fashion. A line was established at C_5 , as notes above C_5 were hypothesized to be above threshold and notes below C_5 were below threshold. Based on this assumption, the rats in Rauscher et al. (1998) would not have heard 1913 (69%) of the 2790 notes in the first movement.

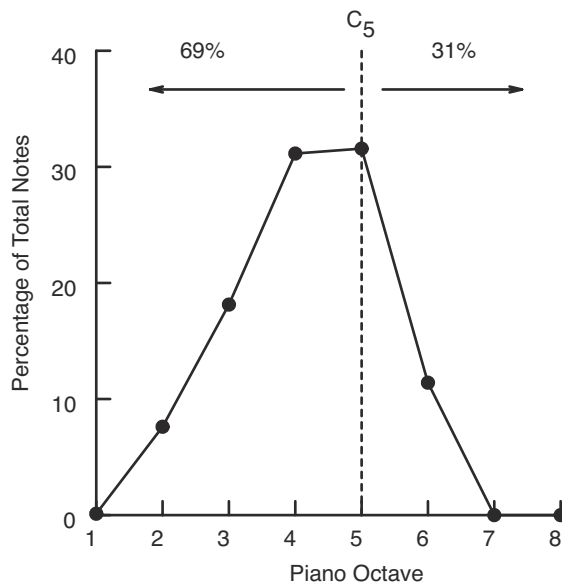


Fig. 4. Distribution of notes in the first section of Mozart's piano sonata K. 448. Each point shows the sum of notes in an octave divided by the total number of notes in the first section of K. 448. The note C_5 (C in the fifth octave) has a frequency of 523 Hz and marks the likely border between inaudible notes (69%) and audible notes (31%).

Discussion

Did the Rauscher et al. rats show a Mozart effect? The evidence is against this conclusion. Exposure to the music in utero would have been ineffective because rats are deaf as newborns. What did adolescent rats hear when the Mozart piano sonata was played? A comparison of human and rat audiograms indicated clear differences between the two species. The range of hearing for rats is shifted to higher frequencies, relative to humans. In contrast, the frequency values of piano notes are located where human hearing is sensitive. The present analysis suggests that rats were deaf to much of the hypothesized enrichment effects of the music because more than half of the notes in the sonata were below absolute threshold for the rats in Rauscher et al. (1998). This is a conservative estimate because the effects of additional noises, such as the masking effects of a ventilation fan, were not included in the estimate.

The conclusion that the rats in Rauscher et al. (1998) were deaf to much of the music permits one to explain one puzzling result from the study. Rauscher et al. found that there was no effect of the music that was played in the maze. This was an odd finding because standard animal learning work would have suggested that subjects should have been disrupted by a change in their usual sound environment (i.e., generalization decrement). The lack of disruption would be consistent with the suggestion that rats heard little of the music, and therefore were not affected by the change in music in the maze.

What explains the positive findings by Rauscher et al. (1998)? The groups may have been systematically different for reasons other than music exposure. Remember that the Mozart-reared rats showed significantly less errors on the first day of training. This difference suggests that the Mozart-reared group was behaving differently from other groups at the start of maze training. An analysis of the Rauscher et al. procedure suggests two factors that could have produced groups with pre-existing differences. First, their design violated the principle of random assignment of rat pups to music-rearing condition. All offspring from a particular mother were assigned to the same music condition. If a rat was impregnated in the presence of the Mozart sonata, then all her offspring would be assigned to the Mozart condition. This procedure introduces the problem of a "litter effect," that is, the offspring of a mother tend to be more similar to one another than to rats in other litters because of characteristics they inherit from the mother and their similar prenatal and postnatal environments (Caldji, Diorio, & Meaney, 2000; Catalani et al., 2002; Pryce & Feldon, 2003). Assignment of all offspring to the same condition confounds litter differences with listening-group differences. The immediate difference in

error rates between the Mozart-reared group and the white-noise group may reflect litter differences between the groups that affected learning rate.

One means by which a litter effect would be translated into a maze-learning effect would be through differences in emotionality between litters. Early stress results in changes in emotionality of offspring and affects learning rates in adult rats. Mild prenatal stress of the mother will result in offspring with reduced fear reactions and increased learning rates (Fujioka et al., 2001). Increased levels of prenatal stress may produce a reversed pattern (Lehman, Stohr, & Feldon, 2000). The impact of a stress manipulation would depend upon the emotional reactivity of the individual. Importantly, individual differences in emotional reactivity among rat mothers are transmitted to their offspring (Caldji et al., 2000). The most common postnatal stress manipulations involve handling of the rat pups by experimenters and periods of separation of pups and mothers (Pryce & Feldon, 2003). At least the first condition was present in the Rauscher et al. experiment. (A typical control condition, and the typical method to reduce a litter-effect problem, is to cross-foster, i.e., spread the members of any one litter evenly among all mothers. Rauscher et al., 1998, did not do this because they thought they were studying the effect of music on the developing fetal brain.)

A second problem comes from the experimenter's construction of the final groups. Subjects were culled from groups *after* group assignment was known. The final three groups contained the same number of subjects, evenly divided between males and females. Creation of each group required culling of some number of subjects by the experimenter. Experimenters would not be blind to group assignment of the offspring during culling because the mother's listening condition was established already. Therefore the experimenter may have introduced some selection artifact during the culling operation that affected the final nature of the groups.

One selection artifact that would be of concern is inadvertent attention to the distance between anus and genitalia, the anogenital distance (AGD). From birth, rats are classified reliably as male or female based on observation of the AGD (Gallavan, Holson, Stump, Knapp, & Reynolds, 1999). AGD is a marker that indicates hormone exposure also, with increased AGD indicating increased androgen exposure. Even female fetuses will be "masculinized" by developing in close uterine position to male fetuses, the "intra-uterine position" effect, and this exposure would be reflected by an increased AGD (Meisel & Ward, 1981; Richmond & Sachs, 1984; see Drickamer, 1996, for a recent review). Exposure to prenatal androgens increases learning rate in spatial mazes in both male and female rats (Isgor & Sengelaub, 1998). Hence, inadvertent attention to an increased AGD could lead to the selection of a group of males and females that would show better spatial learning.

A combination of both litter effects and selective culling could produce groups that would be systematically different in a fashion that would affect the rate of learning by the group in the maze. For example, any one individual rat may be more fearful to being placed in the maze than another rat. The *litter-effect* problem is that this first individual rat may be in a music group that contains brothers and sisters who may have a similar level of emotional reactivity, whereas the other rat is in a different music group that is composed of brothers and sisters who share that other rat's level of emotional reactivity to the situation. The *culling* of the groups may have led to the elimination of pups who appeared "different" from their littermates, which would magnify these litter effects. Thus superficially trivial and innocent steps could produce groups that would learn to run mazes at different rates independent of the assigned listening condition.

The preceding paragraphs suggest plausible speculations of how systematic learning-rate differences among groups could have been produced inadvertently by the Rauscher et al. procedure. The most plausible sequence would depend on a careful analysis of concrete details of the procedure. This may prove difficult to do because many important details may have gone unrecorded, such as the number of brothers and sisters in a group, or objectively undefined, such as the rule used to choose the animals to be culled.

The historical record makes clear that seemingly trivial deviations from true random assignment can have a major effect on results. Brady, Porter, Conrad, and Mason (1958) reported that monkeys who were required to lever press to avoid shock developed stomach ulcers more quickly than did yoked control subjects that had no control over shock rate. Brady's (1958) vivid analogy that the responding monkeys were like busy "executives" suffering from the stress of decision making was a captivating image. However, the general finding to come from this type of experimental situation was the reverse result (Weiss, 1971). The subjects who had no control over the amount of shock or were unable to predict its occurrence were the ones who suffered the most ulcers. Weiss concluded that Brady's atypical result likely came from a failure to use random assignment of subjects to condition. Monkeys who learned the avoidance task most quickly in a pretest were assigned to the executive role and subsequent work demonstrated high-responding subjects were the ones most likely to develop ulcers.

Rauscher (1999b) and Shaw (2000) suggested that the demonstration of the Mozart effect in rats rules out a procedural or cultural explanation of their results with humans. The present analysis suggests there was no Mozart effect in the Rauscher et al. (1998) study because the rats were deaf to the majority of notes in the sonata played in their experiment. An alternative explanation of their results is available because the design of the experiment confounded familial differences with group assignment and subjects

were culled after group assignment was known. Either design problem could explain the different performances by the groups in a maze task. There is still no scientific reason to base intellectual enhancement programs on the existence of the Mozart effect.¹

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