ORIGINAL ARTICLE

The effects of parametric speaker sound on salivary hormones and a subjective evaluation

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Abstract

OBJECTIVE: Recently, a parametric speaker system has been developed. However, the safety of the parametric speaker for the human body has not yet been demonstrated. Therefore, we studied the effects of parametric speaker sound on salivary hormones and carried out a subjective evaluation.

METHODS: Nine male subjects participated in this study. They completed three consecutive sessions: a 20-min quiet period as a baseline, a 45-min mental task period with either a general or parametric speaker, and a 20-min recovery period. The subjects were evaluated by the salivary cortisol and chromogranin A (CgA) concentrations. In addition, they took the Kwansei-Gakuin sleepiness scale (KSS) test before and after the task and also a sound quality evaluation test after it. Two experiments, one with a general speaker (general condition) and the other with a parametric speaker (parametric condition), were conducted at the same time of day on separate days. To examine the effects of the parametric speaker, a two-way repeated measures ANOVA (speaker factor and time factor) was conducted.

RESULTS: The results showed that the cortisol concentration was significantly lower during the parametric condition than during the general condition. Furthermore, the sound quality evaluation found a "warm" sensation during the parametric condition to be lower than that during the general condition. A "noisy" sensation during the parametric condition tended to be higher than during the general speaker. However, the CgA concentration and the KSS score were not significantly different for either the speaker factor or the time factor.

CONCLUSION: The results suggested that the burden of the parametric speaker was smaller than that of general speaker, especially on the HPA-axis in the endocrine system.

INTRODUCTION

The parametric speaker is a sound system that can maintain a very sharp directivity by using an ultrasonic wave. This characteristic of the parametric speaker has been reported in many studies since Westervelt (1963) first reported about the parametric speaker. It is known that the parametric speaker sound is heard relatively well around ± 30 degrees in the front of the speaker and that it is sharper than the sound of a general speaker.

Recently, the parametric speaker has been used for various situations such as the information tool in a museum and the traffic information apparatus in a station for people with visual impairments. However, the effects of parametric speaker sound on the endocrine system in humans is not yet clear.

According to previous studies (Tomei *et al.* 2000; Melamed & Bruhis 1996; Liu *et al.* 2006), noise influences both the cardiovascular and endocrine system. Furthermore, independent lines of research have shown deleterious effects of noise exposure on the body, particularly on the endocrine stress system (Kirshubaum and Hellhammer 1994). Several studies have demonstrated that the secretion of salivary stress biomarkers like salivary cortisol and salivary chromogranin A (CgA) increased under different stress conditions (Takai *et al.* 2004; Miyakawa *et al.* 2006; Nater *et al.* 2006; Hebert & Lupien 2007; Hellhammer *et al.* 2009).

Cortisol is the principal hormonal product of the human hypothalamic pituitary adrenal (HPA) axis, a close-looped endocrine system. Previous studies reported increased cortisol concentrations during the anticipation of stressful experiences such as public speaking (Basset *et al.* 1987), academic examinations (Maes *et al.* 1998: Ng *et al.* 2003) and dental procedures (Miller *et al.* 1995). In addition, the cortisol has recently been suggested as a useful parameter to measure noise-related stress. (Bigert *et al.* 2005). Clow *et al.* (2004) reported that the cortisol biomarker may represent a relatively stable substance.

By contrast, it has been shown that the CgA is a soluble protein and its concentration can be measured in saliva (Nagasawa *et al.* 1998: Nishikawa *et al.* 1998). The biomarker CgA has proven to be a reliable stress marker that reflects the activity of the sympathetic adrenomedully system (SAM axis) (Miyakawa *et al.* 2006). Some studies reported a rapid and sensitive elevation of salivary CgA in response to psychosomatic stressors such as public speaking and driving a vehicle (Nakane1998, 2002).

Therefore, we used salivary hormones such as salivary cortisol and CgA in a laboratory experiment to investigate the effects of parametric speaker sound on the endocrine system of the human body. We also carried out a subjective evaluation.

METHODS

Subjects

Nine male healthy students (23 ± 1. 5 years, 169 ± 5. 41 cm, 59 ± 4. 3 kg) participated in this study. They were asked to refrain from hard exercise and drinking caffeinated beverages during the 2-h period immediately preceding the experiment. Since nicotine has been shown to activate the HPA-axis in physiologically relevant doses, subjects were not allowed to smoke on the test day and were asked to maintain their regular sleep-wake cycle. The subjects performed an auditory test (ITERA, GN Otometrics) before the experiment. Their hearing ability was confirmed to be normal. All subjects gave fully informed consent to participate in this study. Their physical characteristics are shown in Table1.

Protocol

The experiments were conducted in a soundproof room. Two experiments were conducted at the same time of day on separate days and under the same conditions with the exception of the speaker condition (the general or parametric speaker). Subjects were asked to relax for at least 15 min after they arrived at the soundproof room. Subjects completed three consecutive sessions: a 20-min quiet period as a baseline, a 45-min mental task period with the general speaker or parametric speaker, and a 20-min recovery period. Subjects were told to rest and physically relax throughout the experimental period. The experimental protocol is shown in Figure 1.

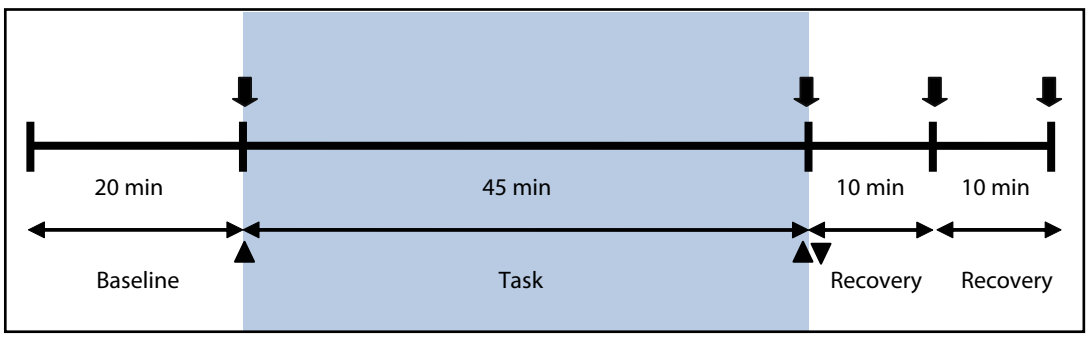

Fig. 1. The protocol of the experiments
⬇: salivary picking, ▲: KSS , ▼: sound quality evaluation

The order of the two conditions (general or parametric) was counterbalanced between the subjects. A salivary sample was taken four times, i. e. , before the task, immediately after the task, 10 min after the task, and 20 min after the task.

Mental task

The mental task consisted of normal sentences and deviant sentences coming from the speaker. Subjects were instructed to judge whether a sentence was true or false and to push a button to indicate that as quickly as possible. The sentences (in Japanese) were made by a text-to-speech synthesis software (SMART TALK Version3, OKI). For example, a normal sentence was " shounen wa toshokan ni itta" (a boy went to the library). In this case, the subjects were asked to push a 'red' button. By contrast, a deviant sentence was "shounen wa ringo ni itta" (a boy went to apple). In this case, the subjects were asked to push a 'blue' button. The Leq of the sound generated by the general speaker was 72. 4dBA, and the Leq of sound generated by the parametric speaker was 72. 3dBA. The background Leq of the soundproof room was 52. 2dBA. The output characteristics of the general speaker and the parametric speaker were almost same, as shown in Figure 2.

Analysis of salivary stress biomarkers

In a previous study, it was verified that cotton Salivettes interfered with cortisol concentration and that cotton-based devices artificially reduced free cortisol concentration (Gröschl *et al.* 2006; 2008). Therefore, in collecting salivary samples, we did not use Salivettes but plastic tubes instead. Saliva samples were immediately stored at –28 °C. They were later thawed and centrifuged for 15 min at 3 000 rpm and processed according the manufacturer's instructions. The cortisol was determined by EIA especially designed for the assay of cortisol in saliva (Salimetrics, USA). The cortisol was expressed as μg/dL. In addition, the CgA concentration was used as the salivary Chromogranin A kit (YK070 Human Chromogranin A EIA, JAPAN) in the analysis. We determined the saliva CgA concentration by correcting the value of the total salivary protein measured in the sample. The concentration of protein in the saliva was based on the Bradford method. CgA activity was expressed as pmol/mg.

Questionnaire for the sound quality evaluation and KSS

For the sound quality evaluation, the subjects were asked to record their responses with the visual analogue scale (VAS). The 11 items for sound quality evaluation

Tab.1. The physical characteristic of the subjects.

The subjects	Age (yr)	BMI	Height (cm)	Weight (kg)
Sub 1	21	21.1	160	54
Sub 2	22	22.3	164	60
Sub 3	24	24.2	165	66
Sub 4	23	18.7	170	54
Sub 5	23	23.0	168	65
Sub 6	22	19.3	172	57
Sub 7	25	20.1	170	58
Sub 8	25	20.8	170	60
Sub 9	21	17.8	179	57
Mean±SD	**23 ± 1.5**	**20.8 ± 2.10**	**169 ± 5.41**	**59 ± 4.3**

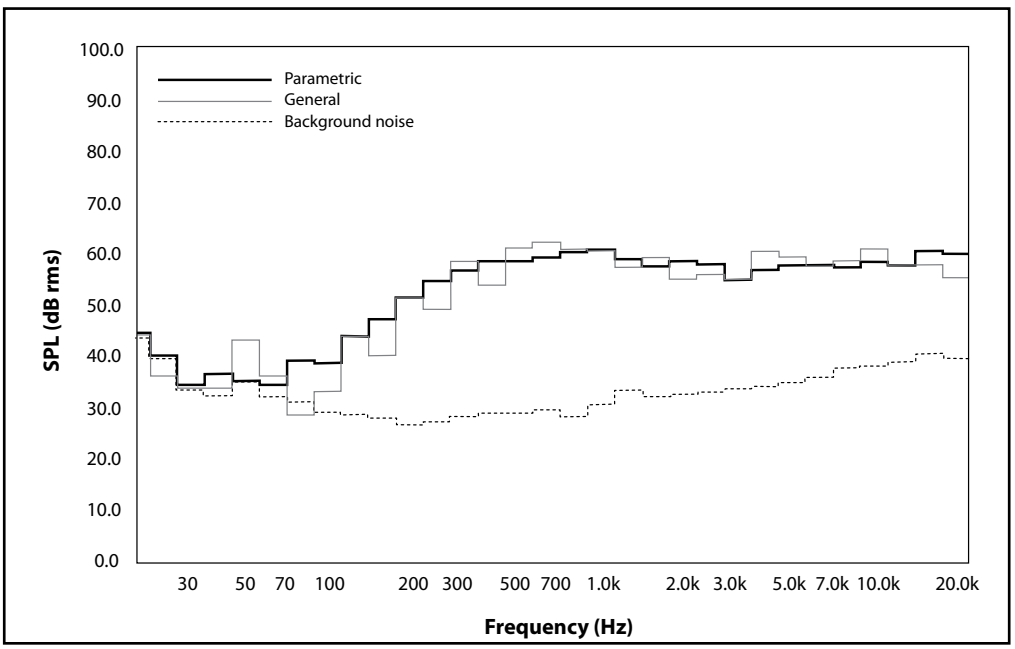

Fig. 2. The output characteristic and picture of the general speaker and parametric speaker

Tab. 2. The sensations of sound quality evaluation.

The sound quality evaluation sensations	parametric	vs general	*p*-value
Hardness	5.777	4.844	0.343
Annoyance	5.177	4.422	0.454
Tune	4.933	5.233	0.673
Volume of sound	4.444	3.422	0.162
Warm	3.233	5.011	0.082 +
Comfort	4.111	4.666	0.538
Noisiness	3.955	3.111	0.065 +
Clearness	3.766	4.544	0.327
Mellifluence	3.988	4.733	0.531
Audible	3.933	4.977	0.195
Information collecting ability	4.411	4.522	0.903

+ : p<0.1

are shown in Table 2. The Kwansei-Gakuin sleepiness scale (KSS) was used to assess subjective sleepiness. Value on the scale concerning drowsiness was determined from answers to 22 questions. The higher the total, the more drowsy the subjects felt.

Statistical analyses

For the cortisol and CgA, a two-way repeated measures ANOVA (Speaker factor × time factor) was conducted. When a significant F value was found, we performed a Student-Newman-Keuls as a post-hoc test. By contrast, data from the subjective evaluation of the general speaker with the parametric speaker were compared using the paired t-test. All statistical analyses were performed using SPSS 11. 0J (SPSS, Japan). Differences with values of $p<0.05$ were considered significant. Data are shown as mean ± standard error of the mean unless otherwise stated.

RESULTS

Figure 3 shows the results of cortisol concentrations. The main effect of the speaker factor was significant ($p<0.05$). The cortisol concentration during the parametric condition was significantly lower than that during the general condition. However, the main effect of the time factor was not significant (Figure 4). The CgA concentration was not significantly different between the speaker condition and the time periods (Figures 5 and 6). Some subjects showed a prolonged elevation in their CgA levels; others showed either immediate recovery or no effects. For the "warm" sensation from the sound quality evaluation, the score of the parametric speaker was 3. 23 ± 1. 95, which tended to be significantly lower than that of the general speaker, 5. 01 ± 2. 42 ($p<0.1$). For the "noisy" sensation, the score of the parametric speaker, 3. 95 ± 1. 77, tended to be significantly lower than that of the general speaker, 3. 11 ± 1. 59 ($p<0.1$, Table 2). The results from the KSS test were not significantly different between the speaker conditions and time periods.

DISCUSSION

The present study is the first report on the effects of parametric speaker sound on salivary cortisol and CgA concentrations. First of all, it is worth noting that the parametric speaker sound was efficient in attenuating biomarker responses to mental stresses. A significantly lower salivary cortisol concentration was observed during the parametric condition than that during the general condition. By contrast, a two-way repeated measured ANOVA on cortisol concentration showed no significant effects on the time factor (Figure 4). Previous human and animal studies which found cortisol increases with noise exposure used either a longer exposure time, higher noise levels, or both (Melamed & Bruhis 1996; Herbert & Lupien 2009). In addition, it has been suggested that cortisol secretion may be related to the kind of stress, exposure time and intensity of the stress. Furthermore, acute and chronic stress have been reported to increase the activity of the HPA axis, with a subsequent increase in cortisol concentrations (Al`Absi *et al.* 1997; Vedhara *et al.* 1999). Nakane (1999) reported that cortisol secretion reached its maximum level right after a speech task and intense exercise. Some investigations have evaluated the effect of noise on cortisol concentrations. High levels of chronic noise exposure (85 to 95 dB L_{Aeq}) were associated with elevated cortisol concentrations as measured in urine samples taken three times a day for one week (Melamed *et al.* 1996).

The results of these reports corresponded with our study, which indicates that salivary cortisol can be used to evaluate the stress response to the speaker sound. The sound of the parametric speaker contains an ultrasonic wave of 40 kHz as the transmitted wave. The sound of both speakers had the almost same frequency characteristics and sound pressure levels, as shown in Figure 2. Therefore, we estimate that the low cortisol concentration during the parametric speaker condition was due to the superdirectivity of the parametric speaker. We also estimate that possible stress from the superdirectivity might not act as a stressor. In other words, we verified that the parametric speaker's burden was lower than that of the general speaker on the HPA axis of the endocrine system.

Recently, it has been shown that salivary CgA is produced by the human submandibular gland and secreted into saliva and that it can be considered a sensitive and reliable index for evaluating psychological stress (Saruta *et al.* 2005). In previous studies, changes in levels of salivary CgA have been examined in situations such as oral presentations and driving on highways (Nakane *et al.* 1998; 2002). Their results showed that, in short-term

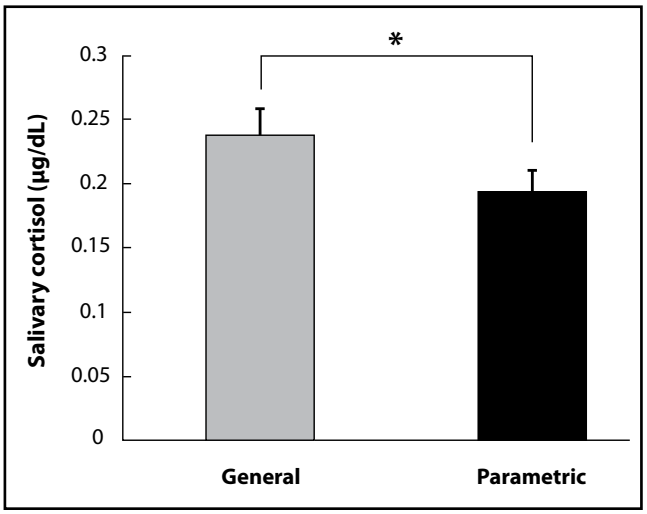

Fig. 3. The salivary cortisol in the parametric speaker and general speaker.

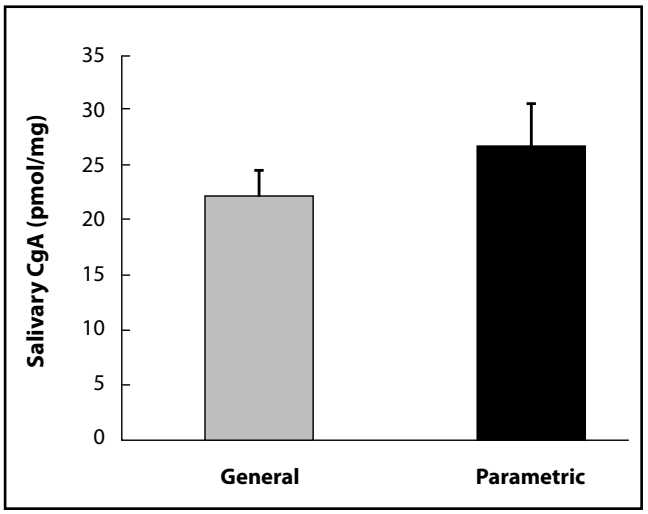

Fig. 5. The salivary CgA in the parametric speaker and general speaker (n. s).

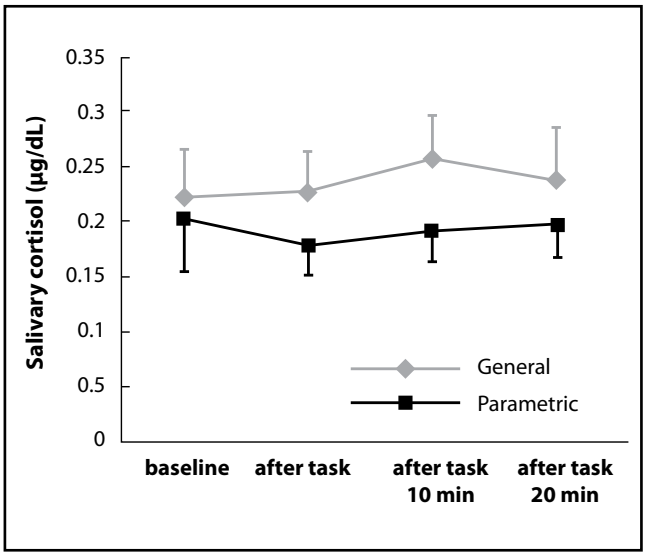

Fig. 4. The comparison of the salivary cortisol in the parametric speaker and general speaker (n. s).

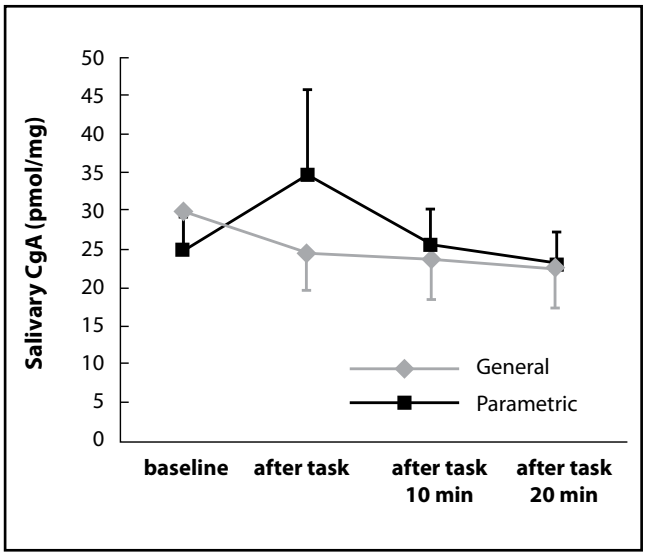

Fig. 6. The comparison of the salivary CgA in the parametric speaker and general speaker (n. s).

stressful situations, salivary CgA levels increased and peaked immediately after a task and then decreased gradually. By contrast, Dimsdale *et al.* (1992) suggested that CgA was stable and slow to respond within the normal physiological range, which occurred in situations of mild mental stress.

In the present study, the CgA concentration, which reflects the SAM axis, was not significantly different between the parametric speaker and general speaker conditions. However, the cortisol concentration, which reflects the HPA axis, was significantly lower during parametric speaker condition than during the general speaker condition. It might be suggested that a possible cause of these different results for the same stress is that there are different response pathways.

In addition, this result might be attributed to the following. The concept of mental stress includes both positive (eu-stress) and negative (di-stress) aspects (Selye 1978). Toda *et al.* (2007) has reported that salivary CgA concentrations are a good index of eu-stress and that moderate eu-stress results in a significant increase in this parameter. We suggest that the parametric speaker sound might be considered as negative stress (di-stress). Another reason for the inhomogeneous distribution of results that we obtained may be the poor stability of this metabolite in the same matrix (Bender *et al.* 1992). Large individual differences have been found in changes in salivary CgA levels in response to noise exposure (Miyakawa *et al.* 2006). Some subjects in the present study showed a prolonged elevation in CgA

levels, while others showed either immediate recovery or no effects. It seems reasonable to suppose that these individual differences correlate with different physiological sensitivities to noise.

In the sound quality evaluation, we verified that the "warm" sensation during the parametric condition tended to be lower than that during the general condition. Furthermore, the "noisy" sensation during the parametric condition tended to be higher than that during the general condition. However, the KSS result was not significantly different between speaker conditions and time factors.

In conclusion, our study is the first report to demonstrate parametric speaker sound effects on the endocrine system. We verified that the burden on the endocrine system of the parametric speaker sound was lower than that of the general speaker sound. We expect that these results will be useful for setting parametric speaker standards and for applications such as announcements in museums or surgery rooms. It remains necessary to conduct further experiments on the effect of parametric speaker sound on the endocrine system based on changes in the distance and frequencies of the ultrasonic waves.

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