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Effect of Favorite Music on Heart Rate Variability Regardless of Aging

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ABSTRACT

Aim： We aimed to examine the effect of favorite music on heart rate variability (HRV). Additionally, we aimed to confirm whether HRV could serve as an index for evaluating responses to musical stimuli, even in older adults with decreased HRV.

Methods： We examined the effects of three types of music ("favorite music," "sound of waves," and "hard rock music") from different categories on HRV in younger and older participants. We assessed feelings ("fun" and "comfort") during the three musical stimuli and without music using a visual analog scale. HRV was indexed by spectral analysis of low frequency (LF), high frequency (HF), and LF/HF, as well as by the standard deviations of the Poincaré plot of R-R intervals along the minor axis (SD1) and major axis (SD2) of the elliptical distribution, and SD1/SD2.

Results： The rating of "fun" was significantly higher during favorite music compared with other musical stimuli. The rating of "comfort" was significantly higher in the favorite music condition compared with the other musical stimulus conditions, except for sound of waves in the younger group. Furthermore, HRV was significantly decreased in terms of SD2 in both the younger and older groups during the favorite music. We also found significant variations in the LF/HF of the favorite music, SD2 of the hard rock music, and LF of the sound of waves in the older group.

Conclusion： These results suggest that the influence of favorite music on perceived "fun" and "comfort" involved specific effects on SD2 in the Poincaré plot of R-R intervals, regardless of aging. Additionally, these findings suggest that HRV (especially SD2) is useful as an indicator of music that elicits emotions even in older adults with decreased HRV.

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Key words： music listening, heart rate variability, Poincaré plot, age differences

INTRODUCTION

Music has therapeutic effects. Music therapy reduces depressive symptoms and anxiety, increases emotional well-being, and improve quality of life in patients with mental disorders, such as dementia, depression, and schizophrenia[1-3]. Additionally, music was found to reduce motor dysfunction and improve the quality of life in individuals with

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acquired brain injury[4]. These effects are supposedly achieved by activating cognitive and emotional processes[5]. For example, listening to music that you heard frequently in the past activates brain areas involved in episodic memory[6,7]. Musical stimuli also affect the autonomic nervous system, which controls heart rate and respiration[8,9] .

Heart rate variability (HRV) has been widely used as an indicator of autonomic nervous system activity[10,11]. The responses of the autonomic nervous system depend on the rhythm and type of music[12-15]. Cardiovascular function related to HRV is affected by the rhythm and speed of music[16]. Music with faster tempo and more complex rhythm increased respiration rate, blood pressure, and heart rate[16].

Generally, musical interventions have been conducted on healthy teenagers and young adults[12-15]. However, age-dependent alterations in HRV indices have been reported, and HRV and complexity decline with age[17]. These shifts are caused by changes in the cardiovascular system, such as decreased baroreceptor sensitivity, increased left ventricular thickness, and increased vascular stiffness[18,19]. Thus, whether HRV is appropriate for measuring the effect of music on autonomic nervous system activity among older adults is not clear.

Furthermore, the emotions evoked by music vary with age[20,21], and a piece of music may not have the same effects across individuals, although music familiarity and preferences influence positively music-derived emotions such as relaxation and happiness[22,23]. However, previous studies examining the effects of different types of music may not have accounted for the way that emotions induced by music vary according to age and individual preferences. Particularly, no studies have measured the positive emotions induced by familiar or preferred music and assessed the resulting changes in autonomic nervous activity using HRV.

First, we aimed to examine the effect of favorite music on HRV. Second, we aimed to confirm whether HRV could serve as an index for evaluating responses to musical stimuli, even in older adults with decreased HRV. Therefore, we examined the effects of three types of music from different categories, including favorite music, on HRV in younger and older participants.

Methods

Study design

The present study had two groups pre-test/post-test design.

Participants

• Younger age group

We collected the data regarding the younger age group in a previous study[24]. The inclusion criterion for the younger age group was 18 to 25 years of age. Participants were recruited by displaying posters on the bulletin board at The Jikei University School of Nursing. The exclusion criteria were a history of cardiovascular disease that could affect HRV, skin diseases on the chest that could be exacerbated by electrocardiography, and menstruation-related symptoms such as pain that could affect HRV. The recruitment period was from March 1 to 31, 2012.

• Older age group

We collected the data regarding the older age group in the present study. The inclusion criterion for the older age group was 65 years of age or older. The participants were recruited at the "Fall Prevention Seminar", which was intended to decrease falls in older adults. It was open to the general public and held at The Jikei University School of Nursing on February 25, 2017. At the seminar, the purpose and methods of the study were explained orally, and pamphlets (containing information about the purpose and methods of the study) and application forms for study participation were distributed. The exclusion criteria were a history of cardiovascular disease affecting HRV, skin diseases on the chest that could be exacerbated by electrocardiography, inability to travel independently to the research facility, inability to stay in the supine position for approximately one hour, and a lack of decision-making capacity, as judged by recruiters. The recruitment period was from February 25 to March 4, 2017.

Interventions

Auditory stimuli

Three sounds were prepared as auditory stimuli for each participant : favorite music, sound of waves, and hard rock music. Relaxing songs selected by participants were reported to increase feelings of relaxation and to decrease heart rate[22]. Therefore, in this study, we asked the participants to select a favorite piece of music in advance, which was prepared by the researcher for use as stimuli. In addition, we used two types of music : the sound of waves (from the album *3D Real Natural Sounds Wave*[25]) and hard rock music (from the album *Appetite For Destruction* by the band Guns N' Roses[26]). The sound of waves was reported to increase parasympathetic nerve activity (PNA) and to have a relaxing effect[27]. Hard rock music promotes excitement and discomfort by enhancing sympathetic nerve activity (SNA)[22].

Measurement procedure

The intervention and measurement procedures are shown in Figure 1. Each study participant was instructed to fast for 2 hours and to avoid alcohol and caffeine for 24 hours prior to the measurement. Before the intervention, each study participant was asked about their age, sex, medical history, and medications. Each participant was asked to lie in the supine position on a bed in a cubicle separated by movable partitions, with an air conditioner set to 27°C. A bipolar chest lead to measure heart rate was positioned on the participant (PowerLab4/30 ; AD instruments, Dunedin, New Zealand). In spectral analysis, the high frequency (HF)

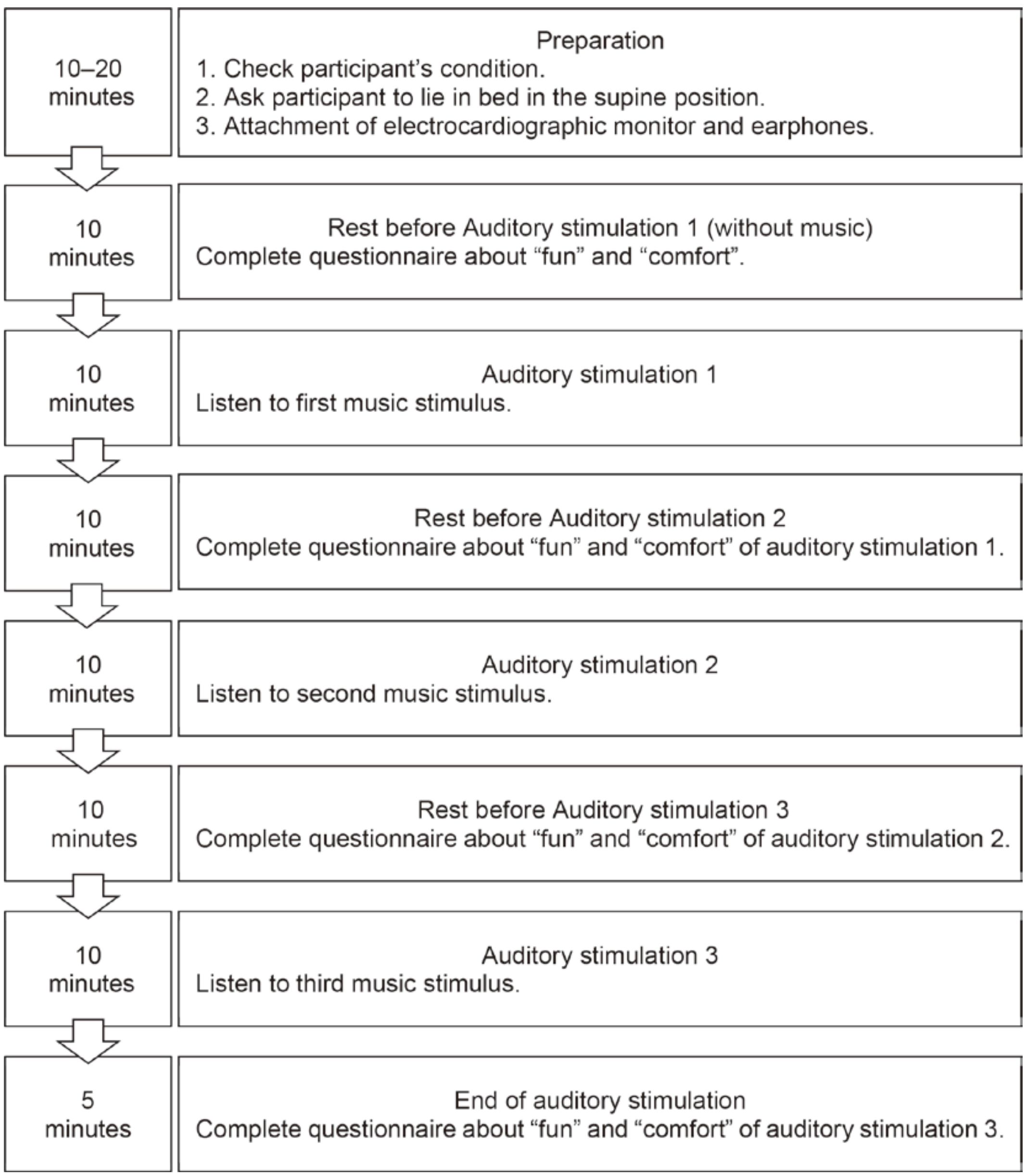

Fig. 1. Intervention content.

band is affected by respiratory rate because it reflects HRV synchronization with respiratory sinus arrhythmias. Specifically, respirations at a rate ≥ 9 breaths/minute (a frequency of 0.15 Hz or higher) are conducted to the sinus node via the cardiac vagus nerve[28]. Younger participants were pre-trained to maintain a respiratory rate of 12 breaths/minute. However, older participants were not pre-trained, because the training may have been psychologically stressful for them, which could potentially affect HRV. Instead, we monitored participants' respiratory rates to check that they did not fall to < 9 breaths/minute using a breathing band. Each participant received three types of auditory stimulation for 10 minutes each. The order of the music stimuli presentation was selected from the following six patterns (non-randomized) : "favorite music, sound of waves, and hard rock music," "favorite music, hard rock music, and sound of waves," "sound of waves, favorite music, and hard rock music," "sound of waves, hard rock music, and favorite music," "hard rock music, favorite music, and sound of waves," or "hard rock music, sound of waves, and favorite music." After each auditory stimulus, the participant answered a questionnaire about the experience of fun and comfort. The auditory stimulation was presented by a portable CD player (KENWOOD MDX-J3-L, Kenwood Corp., Tokyo, Japan) or a portable digital audio player (iPod Touch MKH42J/A, Apple Inc., Cupertino, CA, USA) with stereo headphones (JVC-KENWOOD HP-AL102-W, JVCKenwood Corp., Yokohama, Japan). The sound level was adjusted by the researcher to an appropriate level (50 dB-70 dB) based on the preference of the participant. Before each auditory stimulus, the study participant lay in the supine position without auditory stimulation for 10 minutes. After this rest period but before the first auditory stimulation (Rest before auditory stimulation 1), the study participant answered a questionnaire about fun and comfort in the "without music" condition. Furthermore, after Auditory stimulation 1 and 2 (Rest before auditory stimulation 2 and 3), participants answered the same questionnaire in relation to the immediately preceding music stimulus. The time taken to answer to this questionnaire was approximately 2 minutes, followed by approximately 8 minutes without auditory stimulation. To avoid the influence of previous music stimulus, we selected the data for 400 seconds before the subsequent musical stimulus from Rest before auditory stimulation 2 and Rest before auditory stimulation 3. After Auditory stimulation 3 (End of auditory stimulation), participants answered the questionnaire, which took approximately 2 minutes.

Measurement variables

"Fun" and "comfort"

The "fun" and "comfort" were measured using a visual analog scale (VAS), which is useful as an objective measure of emotions and has been used in music therapy research[29,30]. For the older age group, the VAS was presented as a 100-mm horizontal bar, with "fun" or "comfortable" at the left end and "not fun" or "not comfortable" at the right end, respectively. Each participant made a mark on the line to give their assessment. A larger value indicated a greater degree of fun or comfort. Although the length of the horizontal bar was not exactly equal to 100 mm when printed for the younger age group, the VAS scores were calculated by dividing the length from the right end to the marked point by the total length of the line, and, thus, presented as a percentage. The VAS scores were assessed by an investigator who was not informed about the participant characteristics or intervention methods of the study.

The HRV as an indicator of autonomic nervous system activity

Spectral analysis of HRV is used as an indicator of autonomic nervous system activity. The power of the HF (0.15-0.4 Hz) band in the short term reflects PNA and corresponds to the variation of R-R intervals related to the respiratory cycle, known as respiratory sinus arrhythmia[11,31]. The power of the low frequency (LF : 0.04-0.15 Hz) band in the short term reflects the variation of R-R intervals with a period longer than the respiratory cycle, including the variation of SNA induced by the baroreceptor reflex[11,31]. The LF band is considered by some researchers to be a marker of SNA modulation, whereas other researchers consider it to be a parameter that includes both SNA and vagal influences (PNA)[10]. The LF/HF ratio reflects sympathovagal balance, or sympathetic modulation[10].

For the HRV analysis, data for 400 seconds were extracted from each session. During the auditory stimulation, 400 seconds in the middle of the 600 second stimulus period were selected, and during the no auditory stimulation condition, 400 seconds immediately before the subsequent auditory stimulation were selected. Analyses were performed using HRV analysis software (Lab Chart Pro ver.8, AD instruments), and we calculated the HF, LF, LF/HF, R-R intervals, and mean R-R interval (mRR). The LF and HF bands are described normalized units (nu). This is calculated by dividing the absolute power for a specific frequency (LF or HF) band by the total absolute power of the LF and HF bands multiplied by 100.

Another indicator of autonomic nervous system activity is the analysis of R-R intervals using the Poincaré plot, which is a scatterplot of a current R-R interval against a previous R-R interval. This analysis is a quantitative and visual technique that can show beat-to-beat variability as well as overall heart rate variability[32] . To analyze the Poincaré plot, the nonlinear measurements, SD1 and SD2, can be derived by fitting ellipses to the scatterplots. The SD1 is the standard deviation of the distance of each point from the $y = x$ axis, which indicates the short-term HRV and is correlated with HF. The SD2 is the standard deviation of each point from the $y = -x + 2$ average R-R interval, and reflects short- and long-term HRV as well as correlating with the LF band[11]. Because the number of R-R intervals in the 400-second period varied from case to case, we standardized the datasets used for the Poincaré plot to the smallest number for 300 beats. Outliers in the R-R interval datasets were identified using the hadimvo command in Stata/IC version 16.0 (StataCorp, College Station, TX, USA). The hadimvo command is an algorithm proposed by Hadi[33] as an approximation procedure for minimum volume ellipsoids. After outliers were excluded, SD1 and SD2 were calculated[34].

Statistical Analysis

Changes in the VAS score and HRV during the "favorite music," "sound of waves," and "hard rock music" conditions were examined in the older and younger age groups, and the VAS and HRV measurements from the "without music" condition were used as the baseline. Statistical analysis was performed using Stata/IC version 16.0. P-values of <0.05 were considered statistically significant.

"Fun" and "comfort"

We used the Wilcoxon signed-rank test to compare the "fun" and "comfort" scores given via the VAS between four conditions : "without music," "favorite music," "sound of waves," and "hard rock music." For these comparisons, the significance level was set at $p < 0.0083$ using the Bonferroni criterion to account for the multiplicity of the test. The Wilcoxon rank-sum test was also used to compare the "fun" and "comfort" scores measured by the VAS between the younger and older age groups.

Indicators of autonomic nerve activity

The Wilcoxon signed-rank test was used to compare the LF, HF, LF/HF, SD1, SD2, SD1/SD2, and mRR in the following three pairs of groups : "favorite music" and "Rest before favorite music," "sound of waves" and "Rest before sound of waves," "hard rock music" and "Rest before hard rock music." In addition, the Wilcoxon rank-sum test was used to compare the LF, HF, LF/HF, SD1, SD2, SD1/SD2, and mRR between the younger and older age groups.

Sample size

In previous studies[12-15], a group size of approximately 12 to 25 participants was needed to show a significant change in a physiological response. Accordingly, the study size was set at 15 to 20 participants for each group.

Ethical considerations

This study was approved by the Ethics Committee of The Jikei University School of Medicine (acceptance numbers : 23-232 (6693), 28-296 (8539), and 31-201 (9700)).

Results

Participant characteristics

The participant characteristics are shown in Table 1. In the younger age group, 15 young adults (14 women and 1 man) with a median age of 19 years (interquartile range : IQR 19-19) were included. None had a history of cardiovascular diseases, and one took over-the-counter cold medication. In the older age group, 18 older adults (15 women and 3 men) with a median age of 78 years (IQR 75-83) were included. None reported a history of cardiovascular disease, but one participant with irregular R-R intervals was excluded. Among them, 15 participants took medication, including an angiotensin II receptor blocker (ARB), α-blocker, calcium channel blocker, diuretic, hypoglycemic drug, H_2 blocker, antitussive, antihyperlipidemic drug, antianxiety drug/hypnotic, antihistamine, and antipsychotic.

Table 1. Participant characteristics and classification of their favorite music

	Younger age group (N = 15)	Older age group (N = 17)
Age, median (IQR), years	19 (19-19)	78 (75-83)
Sex, n		
Female	14	14
Male	1	3
Medication, n		
Angiotensin II receptor blocker	0	4
α-blocker	0	1
Calcium channel blocker	0	7
Diuretic	0	1
Hypoglycemic drug	0	2
H_2 blocker	0	2
Antitussive	0	1
Antihyperlipidemic drug	0	5
Antianxiety drug/hypnotic	0	4
Antihistamine	0	3
Antipsychotic	0	1
Classification of favorite song, n		
Japanese Pop	12	1
Anime song	1	0
Rock and Pop (English)	1	0
Classical	1	8
Traditional-style Japanese song (*enka*, folk song)	0	5
Tango	0	1
Movie soundtrack	0	2

Note. N = total number of participants ; n = number of respondents ; IQR = interquartile range

"Fun" and "comfort"

The classification of favorite music is shown in Table 1. In the younger age group, most of the favorite music was Japanese pop songs with lyrics, released after 2000. In the older age group, favorite music was more likely to be classical music and traditional-style songs with Japanese lyrics that were popular in the 1960s and 1970s, such as Enka (Japanese ballad) and Minyo (traditional folk song). Other music selected by the older age group were movie soundtracks with English lyrics and tango music.

The results of the "fun" and "comfort" ratings are shown in Table 2. In terms of the VAS, the rating of "fun" was significantly higher for the "favorite music" versus other stimuli in both the younger and older age groups (younger age group : "favorite music" vs. "without music" $p = 0.0007$, "favorite music" vs. "sound of waves" $p = 0.0007$, and "favorite music" vs. "hard rock music" $p = 0.0048$; and older age group : "favorite music" vs. "without music" $p = 0.0004$, "favorite music" vs. "sound of waves" $p = 0.0016$, and "favorite music" vs. "hard rock music" $p = 0.0005$). Additionally, the rating of "comfort" was significantly higher for the "favorite music" than the other stimuli in the older age group ("favorite music" vs. "without music" $p = 0.0005$, "favorite music" vs. "sound of waves" $p = 0.0021$, and "favorite music" vs. "hard rock music" $p = 0.0009$). In the younger age group, "comfort" was significantly higher for "favorite music" compared with the "without music" ($p = 0.0022$) and "hard rock music" ($p = 0.0007$) conditions.

In the intergenerational comparison, "fun" during the "sound of waves" stimuli was rated as significantly higher in the older age group ($p = 0.0108$). In addition, ratings of "comfort" during the "without music" and "hard rock music" stimuli were significantly higher in the older age group ($p = 0.0165$ and $p = 0.0299$, respectively).

Indicators of autonomic nerve activity

Table 3 shows the results of the HRV indices. In the comparison of each auditory stimulus group, SD2 was sig-

Table 2. Comparison of subjective feelings among different auditory stimuli and different age groups

		Younger age group (N = 15)			Older age group (N = 17)	
Subjective feeling	Type of sound	Median (IQR)				
"Fun"(VAS%)	"Without music"	51 (47-66)	**		60 (55-77)	**
	"Favorite music"	96 (87-97)	**		98 (95-100)	**
	"Sound of waves"	48 (45-55)	**	*	72 (52-86)	**
	"Hard rock music"	57 (37-90)			71 (58-80)	
"Comfort" (VAS%)	"Without music"	63 (46-70)	**		76 (70-82)	**
	"Favorite music"	95 (80-97)			98 (93-100)	**
	"Sound of waves"	83 (65-94)	**		84 (47-94)	**
	"Hard rock music"	46 (30-65)		*	67 (50-85)	

Note.
N = total number of participants ; IQR = interquartile range ; VAS = visual analog scale ; **Wilcoxon signed-rank test, p < Bonferroni criterion = 0.0083 ; * Wilcoxon rank-sum test, $p < 0.05$

nificantly lower for the "favorite music" than the "Rest before favorite music" condition in the younger ($p = 0.009$) and older age group ($p = 0.0129$). SD2 was also significantly lower for the "hard rock music" than the "Rest before hard rock music" condition in the older age group ($p = 0.0277$). There were significant differences in the LF, LF/HF, and mRR in the older age group as follows : the LF was significantly lower for the "sound of waves" than the "Rest before sound of waves" condition ($p = 0.0495$) ; the LF/HF was significantly lower for the "favorite music" than the "Rest before favorite music" condition ($p = 0.0352$) ; the mRR was significantly higher for the "sound of waves" than the "Rest before sound of waves" condition ($p = 0.0099$).

In the intergenerational comparison, the SD1 and SD2 for all groups were significantly lower in the older age group than in the younger age group (SD1, $p < 0.001$; and SD2, $p < 0.001$), and the SD1/SD2 in the older age group was significantly lower than that in the younger age group during the "Rest before favorite music" ($p = 0.0120$), "favorite music" ($p = 0.0299$), "Rest before sound of waves" ($p = 0.0069$), and "sound of waves" ($p = 0.0246$) conditions.

Discussion

The data of the present study show that SD2 decreased in both the younger and older age groups during auditory stimulation with the "favorite music" stimulus. These findings suggest that the influence of favorite music on inducing "fun" and "comfort" had a specific effect on SD2 in the Poincaré plot of R-R intervals, regardless of aging. This finding also suggests that HRV (especially SD2) may be useful as an indicator of music that elicits emotion, even in older adults with decreased HRV.

A previous study reported that both relaxing baroque music and exciting heavy metal music led to a decreased SD2 compared with no sound[15]. However, this might have been caused by differences in the equivalent sound level (dB) of the music[15]. In that study, the sound level of relaxing baroque music and exciting heavy metal music was 70-80 dB, and white noise (90 dB) was used as another stimulus. In the present study, the sound level was set at a level that was easy for the individual to hear, which resulted in a less intense sound level (50-70 dB), compared with previous studies. Therefore, it is unlikely that the sound level is the only factor modulating SD2.

Two other possible reasons for the decrease in SD2 on the Poincaré plot should be considered. One reason is that emotions induced by favorite music may have affected not only the autonomic nervous system, but also the endocrine system. Although the "favorite music" used in the present study varied in terms of type, tempo, and lyrics, perceived "fun" rated using a VAS was significantly higher than that for the other auditory stimuli (Table 2). First, listening to music that elicits emotion increases the release of dopamine in the striatal regions[35]. This release of dopamine may lead to pleasure and be associated with feelings of "fun" and "comfort" when listening to favorite music. Additionally, beta-endorphins secreted by the hypothalamus-pituitary

Table 3. Comparison of HRV indices among different auditory stimuli and different age groups

	Median (IQR) Younger age group (N = 15)					
HRV index	Rest before favorite music	Favorite music	Rest before sound of waves	Sound of waves	Rest before hard rock music	Hard rock music
LF (nu)	41.0 (24.3-62.8)	38.8 (31.9-54.2)	39.5 (20.9-47.1)	43.8 (31.1-53.4)	35.2 (27.7-50.5)	38.7 (32.9-54.9)
HF (nu)	57.7 (36.3-73.6)	59.1 (43.1-67.1)	53.6 (51.9-76.1)	54.7 (45.7-67.5)	57.9 (46.5-70)	54.2 (43.1-65.5)
LF/HF	0.71 (0.34-1.73)	0.66 (0.5-1.26)	0.76 (0.27-0.89)	0.79 (0.46-1.19)	0.57 (0.35-1.03)	0.67 (0.5-1.22)
Mean RR (ms)	1010 (886-1111)	998 (890-1121)	962 (897-1164)	1002 (927-1086)	1026 (845-1121)	1015 (865-1163)
SD1 (ms)	42.4 (25.6-67.3)	49.9 (31-64.6)	48.5 (31.8-60.5)	53.3 (37-64.9)	52.8 (22.3-64.8)	44.5 (23.2-64.6)
SD2 (ms)	97.1 (70.8-128.3)	78.2 (57.3-112.4)	87.3 (58-99.4)	92.5 (77.7-124.1)	96.8 (61.5-119.8)	100.7 (58-109.2)
SD1/SD2	0.52 (0.34-0.6)	0.53 (0.43-0.65)	0.62 (0.4-0.66)	0.53 (0.42-0.6)	0.51 (0.35-0.63)	0.53 (0.42-0.62)

	Median (IQR) Older age group (N = 17)					
HRV index	Rest before favorite music	Favorite music	Rest before sound of waves	Sound of waves	Rest before hard rock music	Hard rock music
LF (nu)	48.3 (23.2-68.5)	38.8 (24.9-57)	45.7 (33.6-73.1)	26.7 (23-67.3)	44.6 (36.2-58.8)	37.0 (20.7-59.6)
HF (nu)	49.7 (28.2-62.3)	56.4 (40-65.4)	53.0 (24.1-63.1)	65.4 (31.3-68.8)	50.2 (40.7-55.1)	55.3 (37.8-71.9)
LF/HF	0.97 (0.4-2.42)	0.73 (0.35-1.42)	0.84 (0.53-3.03)	0.37 (0.33-2.15)	0.91 (0.6-1.42)	0.63 (0.28-1.58)
Mean RR (ms)	959 (813-1001)	960 (854-1039)	906 (837-1022)	922 (855-1027)	924 (804-1019)	895 (866-1049)
SD1 (ms)	10.2 (7.6-14.9)	9.3 (7.4-12)	10.2 (7.8-16.8)	9.8 (7.4-12)	10.7 (6.9-15.4)	9.3 (6.4-11.9)
SD2 (ms)	36.8 (24.9-47.3)	24.3 (20.2-33.7)	35.0 (25.3-40.6)	25.4 (22.1-37)	29.6 (18.3-46.3)	22.5 (18.9-33.8)
SD1/SD2	0.31 (0.25-0.43)	0.36 (0.23-0.51)	0.33 (0.2-0.45)	0.30 (0.26-0.51)	0.35 (0.22-0.52)	0.39 (0.28-0.54)

	Comparison with rest before each auditory stimulus*[1]						Comparison between age groups*[2]					
	Younger age group			Older age group			Rest before favorite music	Favorite music	Rest before sound of waves	Sound of waves	Rest before hard rock music	Hard rock music
HRV index	Favorite music	Sound of waves	Hard rock music	Favorite music	Sound of waves	Hard rock music	Y-O	Y-O	Y-O	Y-O	Y-O	Y-O
LF (nu)	NS	NS	NS	NS	$p < 0.05$	NS	NS	NS	NS	NS	NS	NS
HF (nu)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LF/HF	NS	NS	NS	$p < 0.05$	NS	NS	NS	NS	NS	NS	NS	NS
Mean RR (ms)	NS	NS	NS	NS	$p < 0.01$	NS	NS	NS	NS	NS	NS	NS
SD1 (ms)	NS	NS	NS	NS	NS	NS	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
SD2 (ms)	$p < 0.01$	NS	NS	$p < 0.05$	NS	$p < 0.05$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
SD1/SD2	NS	NS	NS	NS	NS	NS	$p < 0.05$	$p < 0.05$	$p < 0.01$	$p < 0.05$	NS	NS

Note. HRV = heart rate variability ; IQR = interquartile range ; N = total number of participants ; LF (nu) = normalized low frequency power = LF/(LF+HF) ; HF (nu) = normalized high frequency power = HF/(LF+HF) ; MeanRR = mean value of RR interval time series ; SD1 = standard deviation of the short-term RR interval variability ; SD2 = standard deviation of the long-term RR interval variability ; ms = millisecond ; Y-O = Younger age group vs. Older age group system also increase dopamine release, suggesting that the pleasure evoked by listening to favorite music may be caused via beta-endorphins. Second, adrenaline and noradrenaline should be considered. Music-induced emotion activates the frontal cortex, including the anterior rostral medial frontal cortex and medial orbitofrontal cortex[36]. Activation of these cortices might cause aperiodic and tonic activity in the sympathetic nervous systems via the hypothalamus, considering that they are associated with the physiological aspects of emotional responses. In this potential pathway, adrenaline and noradrenaline are released by the adrenal medulla into the blood, reducing R-R interval variability and decreasing SD2.

Another possible reason by which favorite music could decrease the SD2 is the modulation of respiratory-related activity in the autonomic nervous system via the rhythmic input of the music. The participants listened to their self-selected favorite music. Young participants were most likely to select Japanese popular music, which is fast-tempo music. Thus, the respiratory cycle may have been influenced by the fast-paced rhythm of the music, resulting in a faster and more irregular respiratory cycle. The HRV reflects variations in the R-R interval that related to the respiratory cycle, such as respiratory sinus arrhythmia, and changes in the baroreceptor reflex, which is the longer than the respiratory cycle[11,31]. Although respiratory modulated bursts in the sympathetic and vagal nerves are reciprocally and alternatively active in healthy individuals, they are variable and synchronously active under certain circumstances[37]. In the present study, rhythmic stimulation via listening to favorite music may have interfered with the functional coupling between the autonomic nervous center and the respiratory center, resulting in decreased respiratory modulation of the cardiac sympathetic and parasympathetic nerves, and a decrease in the SD2 of the R-R interval.

In addition to the two possible mechanisms described above, the characteristics of the Poincaré plot should be considered. This plot visualized all points that indicate consecutive R-R intervals, or beat-to-beat variability as well as overall HRV[32], which are reflected as SD1 and SD2[34]. Because SD1 reflects variations in short-term HRV and SD2 reflects variations in short- and long-term HRV[11,34], the effect of slow endocrine transmission on SD2 may have been observed in SD2. Furthermore, the Poincaré plot is depicted independently of frequency-band, and is more tolerant to changes of the respiratory cycle compared with spectral analysis[38]. Thus, it is possible that the non-respiratory cycle induced by emotions listening to the music and the irregular respiratory cycle caused by the rhythm of the music was also detected.

The HRV (especially SD2) can be used to assess the effects of music stimuli, even in older adults with reduced HRV. In the older people, the transmission of the autonomic nervous system to the heart is restricted because of decreased sensitivity of alpha- and beta-adrenergic receptors in the heart and blood vessels and decreased conduction velocity of vagus nerve fibers[39]. However, in the endocrine system, plasma noradrenaline concentration increases with age and the sensitivity of the heart to adrenergic stimulation is maintained, even in the older people[40]. Thus, the endocrine system may have a relatively stronger influence on heart function in the older people, compared with the decreased influence of the autonomic nervous system. Moreover, the emotional responses of older adults may be more sensitive to music compared with those of younger adults, and may be more likely to be influenced by the endocrine system. Music stimuli, particularly familiar music stimuli, can evoke episodic memories and modify emotional states[7,9,35]. Physiological changes via endocrine factors caused by emotional changes are reflected in HRV. When older adults are presented with “happy music,” they are reported to assess their emotional response as more intense compared with younger adults[20]. In the present study, ratings of “comfort” and “fun” using the VAS were higher in the older group compared with the younger group when they listened to hard rock music and sound of waves, respectively. The older adults included in this study tended to have more intense emotional responses to music than the younger adults, which may have promoted endocrine secretion.

Limitations

This study involved several limitations that should be considered. First, we did not strictly control participants’ respiratory rate. Thus, while listening to favorite music, the respiration rate may have changed in accordance with the rhythm of the music. However, we regarded both the direct influences of music on HRV and the indirect influences via the change of respiration rate as effects of music.

Second, we did not exclude participants who had a medical history or took medication, except for those who had arrhythmias or who took medications that were highly likely to interfere with R-R interval variability, such as beta-blockers and antiarrhythmic medications. It has been reported that diuretics decrease HF, LF, and LF/HF[41,42], and angiotensin II receptor blockers increase HF[43,44]. These drugs may have affected the effects of auditory stimulation. In addition, the older age group included those who took hypoglycemic drugs. Diabetes leads to cardiac autonomic dysfunction and has a negative influence on almost all HRV parameters[45]. As a result, HRV indices are likely to be lower for participants with diabetes. Thus, these indices may have been underestimated in the older age group compared with a sample in which individuals with diabetes were excluded. However, we included these participants because of the need to recruit a sufficient sample size.

Third, the older and younger groups had different background characteristics, such as age, medications, and diseases, which may have influenced the comparison of HRV between the two groups. However, the purpose of the present study was to determine whether HRV could serve as an index for evaluating the response to musical stimuli, even in older adults with decreased HRV. Therefore, to show that HRV in the older group had decreased, a comparison with the younger group was necessary.

Fourth, although we used a VAS to evaluate the effect of the "favorite music" stimulus by assessing feelings of "fun" and "comfort," it is difficult to compare the real differences in emotional changes between older and younger people because this type of scale is subjective and relative. The underlying mechanisms by which auditory stimulation with favorite music decreased SD2 are still unclear. Further studies combining electroencephalography, neuroimaging, and other methods of assessing autonomic function are needed. Furthermore, to evaluate the therapeutic effects of preferred music, the long-term effects of such music interventions should be considered.

Conclusion

In summary, "favorite music" that induced "fun" significantly decreased the SD2 in the Poincaré plot. In addition, even though HRV was clearly decreased in the older participants, musical stimulation modulated the SD2 and other indices of HRV. This finding suggests that HRV (especially SD2) could be used as an indicator of music that stimulates emotions.

Conflict of Interest Statement

MM received lecture fees and lecture travel fees from the Centre for Family Medicine Development of the Japanese Health and Welfare Co-operative Federation. MM is an adviser for the Centre for Family Medicine Development Practice-Based Research Network and a program director of the Jikei Clinical Research Program for Primary-care. MM's son-in-law worked at IQVIA Services Japan K.K. which is a contract research organization and a contract sales organization. MM's son-in-law works at SYNEOS HEALTH CLINICAL K.K. which is a contract research organization and a contract sales organization.

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