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Bodily Movements Influence Heart Rate Variability (HRV) Responses to Isolated Melodic Intervals

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Abstract

The present study examines psychophysiological responses to ascending melodic intervals and the specific influences of bodily movement. A total of 15 adult listeners were assessed in 2 conditions with and without voluntary bodily movements during listening to major third and major seventh intervals, while their heart rate was continuously recorded. Heart rate as well as the standard deviation of normal-to normal RR-intervals in the electrocardiogram within a given time interval (SD-NN-RR) served as dependent measures, the latter indicating parasympathetic activation. A repeated measures analysis of variance (ANOVA) revealed a significant interaction between interval and condition. Listening to the major seventh interval led to significantly higher SD-NN-RR values than listening to the major third in the condition without voluntary movement. With movement, these differences were not observed. The study extends previous findings by showing that task demands strongly influence physiological responses to isolated musical materials.

Keywords

melodic intervals, heart rate variability, physiological response to music

Musical intervals (MIs) are often defined as successions or simultaneous occurrences of 2 pitches. MIs are thought to convey musical meaning giving rise to specific sensations including, for example, varying degrees of consonance.[1] MI:s have been considered important building blocks of melodies and thus became subject to theoretic reflection throughout the history of musical cultures.[2] However, there is paucity of research reflecting on aesthetic responses to MIs, in general, and their physiological implications, in particular.[3]

In a study of MI perception using event-related potentials as electrophysiological markers, it was observed that early components in processing different musical intervals were more similar than late components. For example, the so-called P3 component in the event-related potential (ERP) response to a major third (M3) was found to be significantly smaller as compared to a major second or a perfect fifth.[4] The ERP is any measured brain response that is directly the result of a thought or perception, in this case the intervals. Björkvold (1992)[5] has shown that children in early school age prefer to use the major and minor third, and other researchers have shown that preschool children prefer specific intervals (Schellenberg and Trehub 1996)[6]. Such studies indicate that different intervals have differential effects that are mirrored in preferences and reactions. Krantz[7] has used open-ended verbal and nonverbal responses to investigate the psychological meaning of melodic intervals of the major scale. In one study, results revealed qualitative differences in body movement when participants moved to melodic intervals.[8] This study suggested significant difference between the M3 and the major seventh (M7). Movements in response to M7 were judged as repulsive and full of tension, and movements in response to the M3 were judged as more relaxed. In other studies, M7 has been characterized by reactions such as *disharmony* and *tension*, while M3 is often associated with *harmony* and *calmness*.[1,3,7] In the present study, M3 and M7 were chosen to shed further light on their psychophysiological implications.

Physiological responses to musical stimulation have been subject to a wide range of scientific studies with some emphasis on cardiovascular activity. For example, Hyde and Scalapino[9] reported significant increases of blood pressure in volunteers listening to selections of classical music. The authors

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associated these increases with particular passages (stirring notes) in the musical materials. Möckel et al[10] observed within a more comprehensive approach that different types of music elicited differential patterns of heart rate, arterial blood pressure, and hormonal changes. However, with respect to related studies in clinical and nonclinical contexts, the literature remains inconclusive as to the existence of causal relationships between specific structural aspects of musical materials and physiological responses.

Heart rate variability (HRV) is an aggregate measure of cardiovascular activity, which has been applied in a wide range of experimental contexts including music stimulation. Urakawa and Yokoyama[11] investigated physiological responses to physical exercise under the influence of music stimulation. The authors found that during music listening the ratio between low- and high-frequency (LF/HF) components of HRV was significantly higher after exercise than after rest conditions. This was not observed in corresponding conditions without music. The authors concluded that some rhythmic component in the music synchronized with cardiovascular rhythms to enhance sympathetic activity. In a review of research using vibroacoustic music stimulation, Grocke et al[12] concluded that these interventions were successful in reducing blood pressure as well as improving HRV in clinical populations. Bernardi et al[13] observed differential effects of listening to music on HRV in healthy groups of listeners with varying degrees of musical expertise. They also found significant associations between cardiovascular variables and musical tempo. Thus, HRV appears as an effective measure to assess cardiovascular responses to music stimulation. The main goal of this study was to examine psychophysiological responses to listening and moving to 2 melodic intervals using HRV as a marker.

Methods

Participants

A total of 20 women and 5 men, aged 20 to 57, participated. The mean age was 30.2 years. They had no professional background or specific experience in the field of music or movement. Participants gave informed consent prior to the study.

Stimuli

Two melodic intervals (ascending M3 and M7), 2 consonants (M and L), and 2 body-based movements (standing upright and moving the upper limbs with a contracting and an expanding gesture in a moderate tempo) served as experimental stimuli. The intervals were played from a hidden position by the first author on a normally tuned grand piano. They were played in C-major, diatonic scale, and comfortable loudness. The sequence was always C 1 (one second duration)—pause (one second)—interval (one second). The sequence was repeated 3 times followed by a pause of 10 seconds. The presentation of the intervals was repeated for a total of 2 minutes. Participants were asked to stand still and listen carefully to the interval during the first minute. For the second minute of presentation, they were asked to move spontaneously while listening, improvising body movements that were felt appropriate. Unrestricted movement or the use of typical movements derived from previous studies was encouraged: M3 was connected with a round, inward-directed movement, and M7 with a repulsive movement. The spoken information was formalized and consisted of only 2 sentences. The first author who gave instructions for movements also spoke consonants. The presentation of the stimuli was random on 2 levels. First, the order of M3 and M7 intervals was varied. Second, the order of musical, linguistic, and movement stimuli was also quasi-randomized to check for possible order effects.

Stimuli were presented in sequences (see above) and in 2 sessions with a pause of 2 minutes between sessions. Accordingly, each interval could be studied in 2 successive sessions, but the order for M3 and M7 was varied and in both parts the linguistic and the prescribed movements in silence (standing and moving upper limbs) were randomly interspersed with the sound intervals. The study included 4 sessions with 5 participants each time. A registered nurse was responsible for the application of the equipment and the recordings during the sessions. This design allowed us, within a random design, to analyze the effect of the first and second exposure to M3 and M7, respectively, and to do this at first with only minimal movement allowed and subsequently with movement.

The manual presentation of the intervals was supported by previous studies by the first author, involving 229 participants where no significant difference between manually played and pre-recorded intervals was observed.

Procedure

Materials and Data Reduction

The grand piano used was a tuned (A = 440) Steinway. Ambulatory digital electrocardiography (ECG) was recorded from each participant. QRS-complexes were classified by automatic analysis of the digitally recorded ECG signal. The frequency domain of the time series of RR intervals was analyzed with an autoregression method.[14] The mean RR interval of each time series was subtracted and then detrended by applying linear regression. The variable chosen for analysis was SD-NN-RR, which is the standard deviation of normal-to-normal RR-intervals in the electrocardiogram within a given time interval. This is a frequently used total measure of HRV, which gives an overall image of total variation. Most of the variation in SD-NN-RR is due to parasympathetic activation, although there is also a smaller contribution from sympathetic activation.[11,15-17] Registrations were collected and processed, which gave a series of epochs, each lasting for 25 seconds. They were distributed over the whole experimental period and across participants. The epochs could be identified and connected to the different stimuli in 2 ways: first by means of the recorded time when participants pressed the event button on their equipment and second by means of the strict timetable the sessions were run in. The data were reduced and analysis was constructed

Table 1. Heart Rate Variability (nlog Transformed Standard Deviation of RR Intervals Within Each Mid-25 Seconds of Study Interval, SD-NN-RR) During Listening to Major Seventh and Major Third With Nonmovement and Movement, Respectively[a]

		Nonmovement		Movement Allowed	
		M nlog SD-NN-RR	SD	M nlog SD-NN-RR	SD
Average of both trials	M7	3.74	0.33	3.46	0.45
	M3	3.44	0.30	3.64	0.29
		Paired $t = 2.70$, df = 14		Paired $t = -1.64$, df = 14	
		$P = .017$		$P = .123$	
First trial only	M7	3.82	0.37	3.45	0.46
	M3	3.53	0.29	3.64	0.35
		Paired $t = 2.24$, df = 14		Paired $t = -1.86$, df = 14	
		$P = .042$		$P = .084$	
Second trial only	M7	3.66	0.41	3.48	0.56
	M3	3.35	0.50	3.65	0.35
		Paired $t = 1.91$, df = 14		Paired $t = -1.13$, df = 14	
		$P = .077$		$P = .277$	

Abbreviations: M, mean; SEM, standard errors of mean; M3, major third; M7, major seventh; nlog, natural logarithms; SD, standard deviation.
[a]RR is distance between one heart beat to the next. Number of participants = 15. Two-tailed paired *t* tests.

on two 25-second epochs chosen from the middle of the exposure time for each stimulus. This was done in order to eliminate random disturbances at the beginning and at the end of each measurement. Recordings were uncertain in 4 cases, such that these had to be excluded from the sample. In addition, more than 20% abnormal beats (premature contractions or QRS complexes that differed significantly from normal) were noted across conditions in one more participant, which also needed to be excluded. Therefore, measurements from 15 participants were retained for analysis. Participant groups between different conditions were nearly identical with 3 exceptions described in the following: One participant had more than 20% abnormal beats during the first trial's two M7 epochs but normal recordings during corresponding epochs during the second trial. In this case data from the second trial's M7 epochs were used as substitutes for the first trial's M7 epochs. In another participant, the reverse phenomenon occurred and accordingly the first 2 M7 epochs were used as substitutes for the third and fourth. One participant had missing data during the second trial while listening and moving to M3. This was substituted for by the corresponding data from the first trial. Finally, in one participant there were more than 20% abnormal beats during the second trial's listening and moving to M7. This was also substituted for by corresponding data from the first trial.

Statistical Procedures

Since SD-NN-RR shows a highly skewed distribution, this variable was transformed to natural logarithms (nlog). At first a multivariate analysis of variance for repeated measures was performed separately for 2 dependent measures; nlog transformed standard deviation of the RR intervals (SD-NN-RR) and heart rate, respectively. This repeated measures statistic was chosen because the focus in this study is variation in individuals (intra-participant variation). Accordingly the statistic provides information regarding the independent statistical significance of the variation in individuals between different conditions. In the multivariate technique, the statistical significance of each one of the independent variables is tested after adjustment for the 2 other independent variables. Accordingly, the main effects of the explanatory factors (independent variables) were tested for presentation order, movement (no movement/movement), and interval (third/seventh). After this, 2-way and 3-way interactions were examined. If there is a significant 2-way interaction in the multivariate analysis of variance for repeated measures, there is a joint effect for instance of trial number and movement which is sufficiently strong to add significantly to the total variance over and above the main effects. In the final step, the main hypotheses were tested by means of paired 2-tailed *t* tests starting with the combined assessments (means) from the 2 trials and then subsequently for each of the trials. Interval was the focus in these analyses, hence seventh was compared to third separately, during the nonmovement and movement conditions. Effect size (difference in mean divided by mean standard deviation) was calculated for significant (or borderline significant) differences.

Results

Table 1 shows means and standard deviations of nlog SD-NN-RR in the different conditions. The table also shows *t* tests for comparisons between conditions. When the 2 trials are combined, there is a significant difference between the M7 and the M3 during the nonmovement condition. Heart rate variability is more pronounced while the participants listen nonmoving to M7 ($P = .017$). As observed in the separate analyses of the 2 trials, the difference is more pronounced during the first trial than during the second one. The effect size is 0.83 for the first trial and 0.67 for the second one. These effect sizes are small.

Table 2. Heart Rate (HR, beats/min) During Listening to Major Seventh and Major Third With Nonmovement and Movement, Respectively[a]

		Nonmovement		Movement Allowed	
		M HR	SD	M HR	SD
Average of both trials	M7	77.6	9.8	81.3	11.8
	M3	77.0	9.0	75.9	8.5
		Paired $t = 0.46$, df $= 14$		Paired $t = 2.28$, df $= 14$	
		$P = .654$		$P = .039$	
First trial only	M7	76.3	8.7	80.7	12.4
	M3	74.5	8.5	74.5	8.5
		Paired t $= 1.06$, df $= 14$		Paired $t = 2.62$, df $= 14$	
		$P = .309$		$P = .020$	
Second trial only	M7	77.2	77.2	81.9	12.2
	M3	77.6	10.3	77.3	9.3
		Paired $t = 0.06$, df $= 14$		Paired $t = 1.68$, df $= 14$	
		$P = .955$		$P = .116$	

Abbreviations: M, mean; SEM, standard errors of mean; M3, major third; M7, major seventh; HR, heart rate; SD, standard deviation.
[a]Number of participants = 15. Two-tailed paired *t* tests

When the participants are allowed to make movements adapted to the character of the interval, the situation changes. The differences between the intervals are not significant and the direction of nonsignificant difference is even in the reversed direction, with a tendency toward more pronounced HRV during listening to M3, especially during the first trial ($P = .084$). Table 2 shows the corresponding means and standard deviations of heart rate during the different conditions as well as results of *t* tests. There is no difference at all with regard to heart rate between the 2 intervals when movement is not allowed. However, when participants move during listening, the heart rate mean is higher during M7 than it is during M3. The difference is particularly pronounced during the first trial when it is on average 6.2 beats/min higher during the M7 listening plus moving than it is during the corresponding listening and moving to M3. Effect sizes for these comparisons during the first and second trial are small—0.59 and 0.48, respectively. Table 3 shows the results of the multivariate repeated analyses of variance (ANOVAs) for nlog SD-NN-RR and for heart rate. There is a strong interaction between interval and movement affecting both HRV and heart rate when other factors in the equation have been accounted for. However, in the analysis of HRV the interaction arises because there is a difference between the intervals when the participants are not allowed to move. On the contrary, in the analysis of heart rate, it is the combination of movement and listening to M7 that is associated with the high heart rate whereas no difference in heart rate is observed between the intervals when movement is not allowed.

Table 3. Results of Repeated Multivariate ANOVAs

Source of variance	df	*F*	*P*
a) nlog SD-NN-RR			
Total model	63	2.42	.0005
Individual	14	2.30	.066
Movement/no movement	1	0.21	.653
Trial number	1	1.39	.258
Interval; third, seventh	1	0.41	.533
Movement × trial number	1	2.43	.125
Interval × trial number	1	0.03	.871
Movement × interval	1	15.98	.0002
Movement × trial number × interval	1	0.00	.999
b) Heart rate			
Total model	63	8.31	.000
Individual	14	37.61	.000
Movement/no movement	1	3.10	.100
Trial number	1	0.97	.341
Interval; third/seventh	1	3,60	.079
Movement × trial number	1	0.95	.335
Interval × trial number	1	1.18	.283
Movement × interval	1	7.59	.008
Movement × trial number × interval	1	0.01	.909

Abbreviations: ANOVAs, analyses of variance; nlog, natural logarithms.
[a]Repeated Multivariate ANOVAs using (*a*) heart rate variability = nlog transformed SD-NN-RR and (*b*) heart rate as dependent variables and (1) no movement/movement, (2) major third/major seventh, and (3) trial number (1/2) as explanatory variables. Number of observations $15 \times 2 \times 2 \times 2 = 120$.

Discussion

Compared to this study, previous research[13] on HRV reactions to music has been designed and conceptualized differently. Our study suggests that listening without movement to M7 may activate total HRV. Heart rate variability is dominated by rhythms induced by parasympathetic activity. It has been shown that nausea[18] and looking at horror movies[19] or playing nauseating violent television games[20] increases the total HRV, with an increase in the dominating parasympathetic components. It is worth mentioning that there were extraordinarily pronounced reactions to the M7 in 3 participants. One participant exhibited extremely high HRV (with bradycardia and abnormal beats) on all sessions with M7 but reacted normally to other stimuli. Two participants had more than 20% premature contractions or abnormal QRS complexes during listening to M7. Such extraordinary reactions were found exclusively during M7 listening. This shows that M7 in these participants could elicit abnormal heart rhythm reactions with a strong parasympathetic component in these participants who had no known cardiovascular disease. This fact could be of importance in situations where melodic intervals are used as tools in educational or therapeutic processes.

A deep breath particularly if it coincides with increased intrathorax pressure (Valsalva) may also induce temporarily increased HRV. This could be an explanation of the reaction to the M7 in the nonmovement condition. A deep breath may be part of a startle reaction. The increase in HRV as a reaction to the nonmovement session with M7 is particularly pronounced during the first trial. This could be interpreted to mean that there is a parasympathetic startle effect to the unpleasant sound of M7. It seems logical that this effect is less pronounced when the participant is exposed to the same stimulus in the second trial.

In studies of responses to M7 using rating scales as well as free verbal descriptions, this interval was characterized by high negative arousal words; disharmony, disquiet, and tension.[3] M3 on the other hand was characterized by words indicating a calm, harmonious mood. In the previous movement studies, M7 corresponded to high ratings of tension and M3 to moderate ratings in the direction of relaxation. Research on the subjective perception of consonance and dissonance has given robust results. In the assessment of the subjective perception of consonance and dissonance, M7 is classified as a strong dissonant interval, while M3 is classified as a harmonious one.[1] These characteristics of the 2 intervals seem to correspond well to the HRV reactions in our study and might be an essential factor in eliciting the responses.

An important observation is that the difference in HRV between M3 and M7 disappears and even tends to be reversed when participants are allowed to move while listening. Also, while there is no difference at all between M3 and M7, with regard to HR when the participants are not allowed to move, there is a pronounced increase in HR particularly during the first trial of listening to M7 when the participants are allowed to move. It should be pointed out that the session with movement while listening to a given interval always followed the session without movement while listening to the same interval. One interpretation could be that the participant could release feelings of uneasiness induced by M7 by starting to move "according to the music." None of the participants were on medication that could influence HR or HRV, and all participants were in good health.

The body movements performed were not recorded or analyzed. The first author and the nurse wrote down general impressions from the movement sessions. There was a pronounced difference in spontaneous movements in the M3 and M7 situations, respectively. M7 movements were very intense and expressive in various ways, whereas movements to M3 were calmer. It would be of interest to examine HRV reactions to all intervals in detail and compare findings with results from the earlier study.[8]

Some data were lost in individual epochs. In these cases, data were substituted between the 2 trials. Although this substitution has a small effect, it tends to decrease differences between trials. Since our sample was small we decided to analyze only the simplest aspect of HRV, the standard deviation of RR intervals (and expression of variation in heart rate within a 25-second epoch) since the more advanced analyses of total power, LF power and HF power, require larger materials and are more sensitive to artifacts than the standard deviation. The standard deviation is generally accepted, however, as a good measure of total HRV.[16]

The intervals were presented in random order and were randomly interspersed with nonmusical stimuli. These precautions in the design were intended to maximize the surprise effect. The instructions given and the fact that participants moved to the interval together with 4 other persons, in the same big-spaced room, might well have had conditioning effects. This would have been of crucial importance had the study focused on specific and varied reactions on stimuli. We are aware of the conditioning effects but argue that they are of minor importance for the general effect of the movement on HRV, sampled from the 4 different groups of participants presented in this study.

The design consisted of many stimuli, and verbal information had to be given between the different presentations of stimuli. This was done by the first author and not automatically by means of recordings. The presence of a person might have influenced participants. It should be pointed out, however, that the first author had no preconceptions about which cardiovascular reactions to expect. Finally, we are aware that our sample size of 15 is small. The findings have to be verified on larger samples.

Conclusion

Earlier research has shown that there might be typical behavioral−cognitive responses to specific melodic intervals. The results of this study show a significant difference in HRV in responses to the 2 intervals ascending M3 and ascending M7 during passive listening when there is no difference in heart rate. Passive listening to these melodic intervals thus appears to be associated with a small but systematic difference in autonomic nervous system response as measured by HRV. When participants were allowed to move according to the music, these differences disappeared. This extends previous indications that musical intervals differentially affect emotions and cognition to the physiological domain. The results of this small study, thus, encourage further exploration of the nature and mechanism of human responsiveness to these simple musical stimuli.

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Bios

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