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ASSESSMENT OF THE PHYSIOLOGICAL STATE DURING GAIT WITH METRORHYTHMIC STIMULATIONS

Abstract: The study aimed to examine the influence of providing information about reacting to the heard musical stimuli while treadmill walking on physiological signals of participants. The study group consisted of 30 adults: group 1 was not informed how to react, group 2 received an instruction to adjust the frequency of steps to the music. The gait was carried out on a Zebris FDM-S treadmill for various sound stimuli using the Empatica E4 band to acquire electrodermal activity and heart rate. Information about moving to the stimuli did not change how the subjects responded physiologically during the test.

Keywords: subject monitoring, psychophysiological state, EDA, HR, gait, rhythmic auditory stimulation

1. INTRODUCTION

Music, a permanent element of every person's life, affects feelings and functioning by inducing emotional, behavioral, and physiological changes. Experiencing an intense reaction to music, which stimulates proper autonomic systems contributes to the feeling of specific emotional states, is a frequent, repetitive, and universal phenomenon for humans. Despite the high degree of complexity of this occurrence, it is possible to observe the impact of the music on the listener by analysing physiological parameters [2, 12, 13]. This influence manifests in a faster heart rate, slower breathing rate, and reduced skin conductivity [1,8]. Music may affect how the heart works, which can be seen in changes in heart rate and heart rate variability [21]. Skin conductance responses can be used to measure autonomic expressions of emotions, including the music domain. Musical, emotional arousal can elicit and modulate skin conductance responses, but those are not sensitive to emotional clarity [9].

Listening to music is a complicated mechanism determined by brainstem reflexes, critical assessment, emotional spread, mental images, episodic memory, and musical expectations. However, it is not unique to the reception of music but shared by other bodies' cognitive functions [6]. Some types of music elements like rhythmic phrases synchronized with the autonomic changes in physiological signals. Music can convey emotions by causing autonomic arousal during rhythmic fragments of the music [2, 8]. This musical phenomenon is also used in gait therapies, where a musical stimulus guides how to move correctly [19]. Considering the wide range of the body's reactions to music, it is essential to choose it appropriately for the therapy to obtain the best treatment results while ensuring that the music is pleasant for the patient [14, 18]. During therapy, the patient is influenced by many stimuli. It is important to know their impact on the patient and eliminate or limit harmful stimuli.

The aim of the study was to examine the influence of providing information about the way of reacting to the heard musical stimuli while treadmill walking on physiological signals of participants.

2. METHODS

2.1. Research group

The study group consisted of 30 adults without locomotor system disorders. The group was divided into two subgroups:

- group 1 (18 people: 15 females and 3 males, age: 22.4±1.6 years, body mass: 64.2±12.1 kg, body height: 170.3±8.0 cm) - participants were not instructed how to react to sounds heard during the tests,
- group 2 (12 people: 7 female and 5 male, age: 26.4±7.1 years, body mass: 67.9±11.1 kg, body height: 170.5± 8.0 cm) - before the test, persons were instructed to try and adjust their stepping frequency to the rhythm of the music during the tests of gait on the treadmill.

The research took place in Laboratory of Biomechanics of the Human Locomotor System at the Faculty of Biomedical Engineering of the Silesian University of Technology in Zabrze.

2.2. Research protocol

In the experiment, 12 stages were distinguished, during which the subject performed various tasks related to walking and in the presence of different sound stimuli (Table 1). To reduce the impact of fatigue, repeatability of subsequent stages, and to normalize any deviations in physiological parameters, a short pause for the subject followed each experiment stage was introduced.

The gait tests were performed using a ZEBRIS FDM-T treadmill (ZebrisMedical GmbH, Isny, Germany). At the first stage, each participant adjusted their preferred velocity. First, the participant walked on the treadmill with a velocity set around 3 km/h, gradually increasing by 0.1 km/h until the participant reported preferred gait velocity. Next, this value was increased by 1.5 km/h and then gradually decreased by 0.1 km/h until the participant once again reported the preferred gait velocity. This procedure was repeated until the preferred gait velocity was set. This walk allows to set preferred velocity and to get the participant accustomed to the treadmill. Then, two two-minute gait measurements without rhythmic stimuli were recorded for each test subject. During these measurements, in half of the test duration, the walking velocity was changed from the preferred gait velocity (GP) to 20% faster than the preferred gait velocity (GF) or 20% slower than the preferred gait velocity (GS).

The following stages involved the recording of gait accompanied by various types of metro-rhythmic stimulation. During these tests, the treadmill velocity was adjusted to the value of preferable velocity declared by the participant. Before each presentation of a stimulus, the tested participant walked on the treadmill for 30 seconds. After this, a sound stimulus was played, and the participant walked for 60 seconds. The tests were performed with four types of stimulation [15, 16, 17]:

- GA - arrhythmic stimuli played at a rate of 120 BPM, time 4/4, ambient style. There are no accents in the stimulus, and the transitions between the different tones are smooth. The listeners could not sense tempo changes in respect of the effect on audio-motor synchronisation. The music had a relaxing function, which could influence the symmetry and cadence of the gait.
- GR - rhythmic stimuli played at a rate corresponding to gait frequency, determined during tests of preferable gait velocity, time 4/4, motivational music. Rhythmed periodic stimulus with accents in solid parts of the bar (quarter notes in the 1st and 3rd measures) and an 8-bar phrase. Additional non-accentuated rhythmic units were at regular intervals in the weak parts of the bar (quarter notes in the 2nd and 4th measure). The stimulation was motivating, characteristic of music played during sports training (e.g., aerobics).
- GR110 - GR stimuli played at a rate corresponding to gait frequency increased by 10%; the tempo was determined during gait tests at a preferable gait velocity.
- GR200 - GR stimuli played at a rate corresponding to doubled gait frequency; the tempo was determined during gait tests at a preferable gait velocity.

Table 1. Characteristics of experiment stages

Stage no.	Stimuli	Description	Duration [s]
1	none	preferred gait velocity set by participant	60
2	none	20% faster than preferred gait velocity	60
3	none	preferred gait velocity set by participant	60
4	none	20% slower than preferred gait velocity	60
5	none	average gait velocity	30
6	GA	arrhythmic music at a tempo consistent with average gait velocity	60
7	none	average gait velocity	30
8	GR	rhythmic music at a tempo consistent with average gait velocity	60
9	none	average gait velocity	30
10	GR110	rhythmic music 10% faster than average gait velocity	60
11	none	average gait velocity	30
12	GR200	rhythmic music 100% faster than average gait velocity	60

2.3. Data analysis

To acquire physiological signals, the Empatica E4 (Empatica Inc., Boston, United States) was used. This device allows raw recording data. Two signals from Empatica were analyzed: the skin Electrodermal Activity (EDA) and Heart Rate (HR). At the beginning of the study, the examined person was told to wear the device tight on his/her non-dominant hand, with electrodes placed on the bottom of the wrist and lined up under the middle and ring fingers. The device stays on the subject's wrist throughout the whole examination.

2.4. Signal processing

Electrodermal activity (EDA) is one of the most widely used response systems in all areas of psychology, psychiatry, and psychophysiology. It allows measuring the effects on sweat gland permeability, observed as changes in the skin's resistance to a small electrical current or differences in the electrical potential between different parts of the skin [4].

To analyse the EDA signal, primary parameters were determined based on the collected data and literature sources [5, 18]. For each subject, the processing of electrodermal activity consisted of several primary stages. First, the signal was divided into 12 parts to match the steps of the experiment (Table 1). Then, Z-score normalization based on the mean signal value and standard deviation was performed. To denoise the data, the wavelet transform with a maximum level of decomposition of log2N was used, where N is the number of signal samples. To detect Galvanic Skin Response (GSR), the Matlab toolbox distributed under the free GNU GPL license for EDA processing and analysis - EDA-master - was used. It allowed calculating the number of responses and their amplitude in a given part of the signal.

Throughout EDA analysis, it is essential to divide the signal into the tonic, phasic, and noise components [7]. This model proposed by Greco et al. allowed the calculation of a square measure of the discrepancies between the predicted and observed data. For the tonic component, linear regression was determined. This allowed to specify the general character of the analyzed part of the signal (increase/decrease) and compute its variability - the number of intersections of the original signal with the regression line. Additionally, basic parameters were determined for each segment of the analysed signal: the standard deviation (EDA.SD), responses per minute (EDA.rpm), number of GSR (EDA.GSR), the average energy of GSRs (EDA.enGSR), number of significant GRSs (EDA.sigGSR), the average energy of significant GSRs (EDA.avGSR), number of crossing points with regression line (EDA.cross), the square measure of the discrepancies between the predicted and observed data (EDA.obj).

By counting the number of heartbeats per minute (bpm), the heart rate informs about the body's current state, which reflects the work of individual organ systems under the influence of an external or internal factor. Due to this, heart rate can assess the intensity of physical activity or the power of another stimulus affecting the body [20].

In this study, the heart rate signal was determined from the blood volume pulse signal and pre-filtered by the algorithm proposed by Empatica E4. Each signal sample contains average heart rate values computed in spans of 10 seconds. The analysis method and list of parameters were determined based on the literature [3, 5]. First, the analysed signal was divided into 12 parts, depending on the successive stages of the experiment (Table 1). For each of these signal fragments, frames were determined for which parameters were calculated. A regression line was also selected for each frame. The obtained values for individual fragments were averaged to obtain one value for each parameter for each signal fragment. Parameters associated with linear regression were also determined for each fragment without dividing it into frames to reflect the general character of the analyzed signal during a given experiment stage. Finally, the following parameters were determined for each signal fragment: average HR (HR.mean), standard deviation (HR.SD), 20 percentile (HR.20), 80 percentile (HR.80), quartile deviation (HR.QD), linear regression coefficient an (HR.a), linear regression coefficient b (HR.b), the number of crossing with linear regression line (HR.cross).

2.5. Statistical data analysis

First, descriptive statistics have been computed, including mean, standard deviation, minimum, first quartile, median, third quartile, maximum, interquartile range. The procedure was the same for each analyzed variable: if the required assumptions were fulfilled, ANOVA for repeated measurements was performed (sphericity: Mauchly test, normality: Shapiro-Wilk test). If the normality assumption was violated, then the Friedman test was carried out. In case the data in the compared groups were normally distributed, but the sphericity was not fulfilled, ANOVA with Huynh-Feldt Correction was performed. If the effect test gave a statistically significant result, the effect size (eta-squared) was calculated and its value interpreted. Appropriate post-hoc tests were carried out (pairwise Wilcoxon with Holm correction).

3. RESULTS

The results for selected study stages of the average values between the group with and without information are presented in table 2 and 3 for EDA and HR signal, respectively. Bold indicates statistically significant results between the groups.

Table 2. Electrodermal activity signal values averaged for each stage of the experiment

Stage no.	Subgroup	EDA. SD	EDA. rpm	EDA. GSR	EDA. enGSR	EDA. sigGSR	EDA. avGSR	EDA. cross	EDA. obj
2	Group 1	0.69	9.74	9.74	3.77	**8.00**	3.53	11.17	1.05
	Group 2	0.61	10.12	10.17	3.55	**4.50**	3.31	13.25	2.06
3	Group 1	**0.76**	9.02	9.06	3.32	7.67	3.30	11.22	4.73
	Group 2	**0.65**	9.96	10.00	3.33	5.17	3.02	13.00	1.39
5	Group 1	**0.97**	8.48	4.28	3.02	3.61	2.91	8.22	1.70
	Group 2	**0.91**	9.92	5.00	3.05	2.33	2.73	7.33	1.44
7	Group 1	0.96	9.48	4.78	**5.10**	3.94	**4.98**	7.44	**4.45**
	Group 2	0.95	7.93	4.00	**3.38**	2.75	**3.19**	6.51	**0.93**
8	Group 1	0.73	8.65	8.39	4.77	7.72	4.70	**9.06**	0.33
	Group 2	0.74	8.63	8.67	4.24	6.17	4.05	**12.42**	0.26
9	Group 1	0.96	10.14	5.11	**5.61**	4.78	**5.54**	7.56	**4.01**
	Group 2	0.94	7.11	3.58	**3.54**	2.83	**3.39**	7.67	**0.22**

For the EDA signal, it can be seen that statistically different results were obtained between the two study groups for the six study stages (which made up 50% of the whole experiment). Only one of these stages involved the use of rhythmic stimuli (stage 8 - rhythmic music at a tempo consistent with average velocity), the other four were stages of walking at a preferred velocity, and the last one was a stage of walking at a faster than preferred treadmill velocity. Depending on the stage of the experiment, EDA.SD, EDA.enGSR, EDA.sigGSR, EDA.avGSR, EDA.cross and EDA.obj allow distinguishing research groups.

Table 3. Heart rate signal values averaged for each stage of the experiment

Stage no.	Subgroup	HR. mean	HR. SD	HR.20	HR.80	HR. QD	HR.a	HR.b	HR cross
4	Group 1	**107.29**	1.95	**105.31**	**109.25**	1.64	0.02	**106.68**	4.11
	Group 2	**97.17**	1.36	**95.83**	**98.55**	1.12	-0.02	**97.63**	5.92

For the HR signal for only one stage of the study (which made up 8% of the whole experiment), statistically different results were obtained between the two study groups. It was stage 4, for which no sound stimuli were applied, and the velocity of the treadmill changed from the preferred by participants to 20% slower. The parameters allowed to differentiate the study groups at this stage were HR.mean, HR.20, HR.80, and HR.b. For the remaining stages, the cardiac signal parameters were similar for the participants of both groups.

4. DISCUSSION

The instructions given on moving to the heard sounds are not factors that stimulate the subjects' physiological responses. Most of the observed differences between the groups occurred for the stages without music, during which guidance did not apply. During these stages, it is likely that the subjects were more agitated for the reason they waited for the next step of the study with an unknown musical stimulus or tried to mobilize and prepare for it.

Instructions were given to subjects that they should adjust the frequency of taking steps to the rhythm of the stimulus is essential when analyzing the time and spatial parameters of the gait. The gait of participants who are not told how to respond to a stimulus was less variable in the auditory stages, indicating that they did not attempt to synchronize the frequency of taking steps to the pace of heard stimuli [17]. For instructed group, an increase in the frequency of steps taken by about 5% and the shortening of the gait cycle time by 0.05 seconds was observed. The highest gait frequency variability and cadence variation was observed in the instructed group during variously timed stimuli (GR110, GR200) [17]. These results show that the instructed persons attempted to synchronize the frequency of the steps taken to the rhythm of the music. A stimulus with a rhythm at a rate equal to the walking frequency causes symmetrization of stepping time. Still, this phenomenon occurs to a similar degree regardless of whether the subjects were informed how to react or not [16].

The use of music has a positive effect on the gait. Still, it seems appropriate to consider the musical preferences and the patient's reaction to music so that the musical stimulus supports and guides the subject during the examination. The stimuli used in such therapies should be non-burdensome for the respondents and pleasant to receive, so it is essential to detect the slightest signs of stress using physiological signals. It is important to understand how individual sound stimuli affect physiological parameters. The information on how to move does not affect the physiological parameters, so they can assess the behavioral and physiological profile when testing with musical stimuli.

5. CONCLUSIONS

Information on the reaction method to the stimulus does not differentiate the groups because most statistically significant differences in physiological parameters were observed for the parts of the study without the participation of the musical stimulus. Information about moving to the stimuli did not change how the subjects responded physiologically during the test with rhythmic stimuli. The cues given can be considered a parameter that will not affect the physiological results, which the use of auditory stimuli may alter. This information can be significant in therapy using metrorhythmic stimuli, where a specific change in the patient's gait pattern is achieved with the help of appropriate musical practice.

Obtained results show that in similar studies, especially in music therapy, the patient should be carefully informed about taking steps. At the same time, it is possible to use measurements of physiological signals to assess the psychophysical condition of the participant, which will allow to notice and, consequently, to react correctly in situations of participant discomfort.

Future research may focus on examining how individual sound stimuli and their characteristics affect the body's physiology and the resulting gait parameters. It seems equally important to investigate the role of the subject's musical preferences in the change of gait parameters while listening to such a sound stimulus during therapy. One should strive to define a musical stimulus that will properly affect the subject, causing favorable changes in the gait pattern and being pleasant to perceive. Searching for statistically significant differences between the results obtained from the analysis of the collected biological signals would allow getting answers about the influence of sound preferences on music perception and spatio-temporal gait parameters.

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OCENA STANU FIZJOLOGICZNEGO W CZASIE CHODU Z POBUDZENIAMI METRORYTMICZNYMI

Streszczenie: Celem badania było sprawdzenie, czy informacje o sposobie reagowania na słyszane bodźce muzyczne podczas chodzenia na bieżni istotnie wpływają na sygnały fizjologiczne uczestników. W badaniu uczestniczyło 30 dorosłych: grupa 1 nie została poinformowana o tym, jak reagować na słyszane dźwięki, grupa 2 otrzymała polecenie dostosowania częstotliwości kroków do muzyki. Chód rejestrowano na bieżni Zebris FDM-S, a do akwizycji sygnałów fizjologicznych wykorzystano opaskę Empatica E4. Informacje o tym, jak reagować na bodźce nie zmieniały sygnałów fizjologicznych u badanych.

Słowa kluczowe: monitorowanie pacjenta, stan psychofizjologiczny, EDA, HR, chód, pobudzenia metrorytmiczne