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Is heart rate variability (HRV) an adequate tool for evaluating human emotions? – A focus on the use of the International Affective Picture System (IAPS)

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ABSTRACT

Because human emotion varies greatly among individuals and is a qualitative factor, measuring it with any degree of accuracy is very difficult. Heart rate variability (HRV), which is used in evaluations of the autonomic nervous system (ANS), is used to evaluate human emotions. This study examines the validity of HRV as a tool to evaluate emotions using the International Affective Picture System (IAPS). For experimentation, five photos were selected for each of the categories of "happy," "unhappy", and "neutral" from among the images provided by the IAPS. The subjects were required to complete the Self-Assessment Manikin (SAM) after being shown each picture. We extracted the R-R interval (RRI) value of each photo from the PPG, as well as the valence, arousal, and dominance value of each photo from the SAM to analyze their correlation. As results, there was significant positive correlation with valence and significant negative correlation with dominance in the photo simulation associated with the "unhappy" emotion, only when the arousal value exceeded a critical value. Therefore, the findings of this study suggest that it is possible to use an HRV-based evaluation only when a high level of emotion is induced by visual stimulation.

1. Introduction

Recently, many studies assessing human psychological and mental states and measuring emotional changes have been conducted in various fields, including psychology, psychiatry, and neurophysiology (Cernea and Kerren, 2015; Coelho et al., 2010; Sheppes et al., 2015). However, emotion is very difficult to measure quantitatively because it comprises moods that arouse various sentiments that depend on the individual. Caicedo et al. reported that emotional response is typically divided into three components: physiological arousal, motor expression, and subjective feeling. Emotional response can be assessed using physiological arousal with methods that include measurements of changes in factors such as blood pressure, heart rate, and brain waves. Emotional response can also be measured using motor expression through facial expression, voice, and gesture, and using subjective feeling through self-report questionnaires (Caicedo and van Beuzekom, 2006).

Because of convenience and the possibility of assessing mixed emotions, assessments of subjective feeling have commonly been used in studies of emotion. As one of those tools, Lang et al. developed the Self-Assessment Manikin (SAM) scale (Bradley and Lang, 1994). SAM comprises three domains: valence, arousal, and dominance. SAM has been validated by several studies as a useful instrument for assessing personal response to an affective stimulus (Backs et al., 2005; Bestgen et al., 2015), and it has been used in many studies (Betella and Verschure, 2016; Imbir, 2016). However, because of the limitation of SAM as subjective tool, several studies suggested the need of objective measurement tool (Desmet, 2003).

Thus, many researcher suggested HRV to complement the limitation of the SAM because HRV reflect the state of autonomic nerve system. Valenza et al. suggested that heart rate variability (HRV) could be an objective tool to assess emotional responses Valenza et al. (2012) and Lane et al. reported a correlation between a subject's emotional state and HRV (Lane et al., 2009). Yu et al. built an algorithm to identify the emotional state based on Electrocardiogram (ECG) (Sung-Nien and Shu-Feng, 2015). For the expansion of measuring emotions, HRV has also used to measure the social cognition ability (Okruszek et al., 2016; Quintana et al., 2012) or the changes in emotional state after meditation (Tang et al., 2009). In diagnostic area, the quantitative measurement for stability of panic disordered patients (Yeragani et al., 1993), and mood in bipolar patients (Valenza et al., 2014) has used HRV.

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Although HRV is currently used sporadically in experiments that are designed to assess human emotional states, no research has yet verified its validity as a tool for assessing human emotion. This study aimed to assess the validity of HRV as a tool for evaluating emotions by comparing changes in HRV and SAM scores upon visual stimulation.

2. Methods

2.1. Subjects

The experiment was conducted in subjects who were 19–35 years old and did not have abnormal blood pressure or photoplethysmogram (PPG) responses. Potential participants were excluded if they had nervous system disorders, systemic diseases, chronic diseases, such as hypertension or diabetes, skin diseases, injuries in parts of the body that were necessary for study observation, an inability to undergo acupuncture stimuli, or inadequate writing skills for full study participation.

2.2. Setting

The subjects were recruited in Daejeon, Republic of Korea from September to November 2015. The study was approved by the institutional review board of Oriental Medicine Hospital of Daejeon University and was registered in the Clinical Research Information Service (registration number: KCT0001721). The consent of all the subjects was obtained after providing them with an explanation of the experiment. All subjects were prohibited from consuming alcoholic drinks, smoking, and ingesting caffeine for 24 h before the experiment. The subjects participated in the experiment after they had a sufficient amount of sleep. To induce an identical mental state among all subjects, the experiment was begun after their rest period without subjecting them to any stimuli while in dark illumination for 30 min.

2.3. Selection of the IAPS photographs

The tool used for emotion stimulation in this study was IAPS, which is currently used in diverse research areas including the assessment of human emotions and the assignment of experimental tasks (Britton et al., 2006). IAPS, which was developed by Professor Lang, currently includes approximately 900 visual stimuli (photographs) that can be jointly used by emotion researchers. IAPS presents three-dimensional values (arousal, dominance, and valence) of subjects' emotional responses, which are assessed through SAM for each photograph (Bradley and Lang, 1994).

A total of 15 IAPS photographs (5 photographs for each group) were selected based on the following valence values in each group: unhappy (4 points or less); happy (6.3 points or more); and neutral 4.5–5.1 points). Table 1 shows the valence, arousal, and dominance data of the IAPS photographs that were presented (Table 1). Fig. 1 shows the selected photographs (Fig. 1).

2.4. Self-Assessment Manikin (SAM)

SAM is a system used to assess the emotional response to a photograph with drawings provided by the IAPS. The drawings are divided into three parts (valence, arousal, and dominance). With five drawings per part, the drawings were produced to enable assessment on a scale of 1–9 points, including steps between the drawings. The points increase from right to left (Bradley and Lang, 1994). The valence part assesses the subject's emotions over a range from pleasant to unpleasant, the arousal part assesses emotions ranging from calm to excited, and the dominance part assesses emotions ranging from controlled to uncontrolled states (Fig. 2).

Table 1
Data of each photograph presented from IAPS.
Source: International Affective Picture System (IAPS) (Lang, 1999) (http://csea.phhp.ufl.-edu/media/iapsmessage.html)

Type of emotion	Number of photograph	Valence	Arousal	Dominance
Unhappy photograph group	1931	4.00 ± 2.28	6.80 ± 2.02	6.80 ± 2.02
	9410	1.51 ± 1.15	7.07 ± 2.06	2.81 ± 1.99
	3000	1.45 ± 1.20	7.26 ± 2.10	2.99 ± 2.10
	6350	1.45 ± 1.20	7.26 ± 2.10	2.99 ± 2.10
	3170	1.46 ± 1.01	7.21 ± 1.99	2.70 ± 1.89
	Total	1.97 ± 1.37	7.12 ± 2.05	3.66 ± 2.02
Happy photograph group	1931	6.48 ± 2.18	6.99 ± 2.35	4.73 ± 2.68
	9410	6.36 ± 1.70	2.51 ± 2.01	5.72 ± 2.03
	3000	6.44 ± 2.22	7.07 ± 1.78	5.51 ± 2.11
	6350	7.33 ± 1.76	7.35 ± 2.02	4.70 ± 2.66
	3170	7.57 ± 1.52	7.27 ± 2.08	5.47 ± 2.42
	Total	6.84 ± 1.88	6.24 ± 2.05	5.23 ± 2.38
Neutral photograph group	1931	4.83 ± 1.28	2.41 ± 1.80	5.92 ± 2.01
	9410	5.00 ± 0.84	2.42 ± 1.79	6.14 ± 2.14
	3000	4.49 ± 1.03	2.63 ± 1.70	5.97 ± 1.89
	6350	4.87 ± 1.00	1.72 ± 1.26	6.47 ± 2.04
	3170	5.07 ± 1.02	2.30 ± 1.75	6.10 ± 2.04
	Total	4.85 ± 1.03	2.30 ± 1.66	6.12 ± 2.04

All values are given as the mean ± standard deviation.

2.5. Procedure

For emotional stimulation, the International Affective Picture System (IAPS) was used. Selected IAPS photographs were shown to participants for 6 s for each photograph after an interval of 20 s. To assess objective feeling, SAM was used. While the participants completed the SAM scale, HRV was measured during emotional stimulation. The photos were arranged randomly (Fig. 3).

The experiment was conducted after the subjects rested for 30 min. The experiment was conducted in a dark, quiet room with an average temperature of 23 °C and an average humidity of 40%.

2.6. HRV measurement

In this study, HRV was assessed using PPG. After a 30-min rest, a PPG sensor (PolyG-A, LAXTHA, Daejeon, Republic of Korea) was applied to the subject's left index finger. While the photographs were shown to the subject, HRV was measured by the mounted PPG sensor.

2.7. Data analysis

The R-R intervals (RRI) for each photograph were derived from the PPG data after the photographs were shown. In the SAM assessment, the valence score (VS), arousal score (AS), and dominance score (DS) were analyzed for each photo and for each category. In this study, an integrated index was calculated by subtracting 5 from VS and multiplying it by AS. For an unhappy group of photographs, −5 was applied to the valence value to divide the valence values into negative (unhappy) and positive (happy) numbers with 5 as the baseline value. This procedure attempted to more comprehensively assess the SAM values. Moreover, the RRI correlation was evaluated after the arousal value scale was increased by multiplying it by an arousal value that reflected the degree of change in happy and unhappy emotions.

The results of the SAM assessment and RRI were compared using Pearson's correlation for statistical analysis to analyze the validity of HRV. For the statistical analysis, R program (version 3.2.3) was used.

2.8. Subgroups based on arousal

To evaluate differences in correlations between RRI and high/low

Fig. 1. Photographs used in the experiment: A (group of unhappy photographs): 1931, 9410, 3000, 6350, and 3170 in order from the left; B (group of happy photographs): 8179, 5800, 4800, 8030, and 8185 in order from the left; and C (group of neutral photographs): 8179, 5800, 4800, 8030, and 8185 in order from the left. Source: the International Affective Picture System (IAPS).

arousal values, the data were analyzed by dividing the photographs into two categories: those with arousal values of 1) 4.5 or higher and 2) lower than 4.5.

3. Results

Participants were recruited from August to November 2015. A total of 30 subjects (15 males and 15 females) were screened and included in the experiment. Their age ranged from 19 to 35 years, with an average of 23.8 years. Table 2 shows the subjects' characteristics.

When the valence, arousal, and dominance values were derived for each photograph, the subjects assigned the lowest valence (2.48 ± 1.02), highest arousal (5.6 ± 2.15), and highest dominance values (4.83 ± 2.49) to the unhappy photograph group compared to the happy and neutral groups (Table 3).

Between the SAM and the RRI, the results of the analysis revealed a significant correlation with valence (correlation coefficient: 0.32, P-value: 0.08) and dominance (correlation: −0.31, P-value: 0.09) only when the subjects were exposed to stimuli related to a unhappy photograph group (Table 4, Fig. 4). In the happy and neutral groups, the correlation between SAM and RRI was not significant for any value

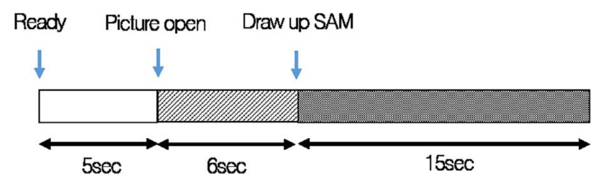

Fig. 3. Experimental procedure. Each photograph was shown for six seconds following five seconds of preparation time. The subjects were asked to complete a questionnaire for the SAM assessment within 15 s after they were shown each photograph. PPG values were continually measured during the procedure.

Table 2
Subject characteristics.

	Male	Female	Total
Participant (n)	15	15	30
Age (years)	24.5 ± 2.7	23.1 ± 3.4	23.8 ± 3.1
Height (cm)	174.5 ± 5.3	163.1 ± 4.7	168.8 ± 7.5
Weight (kg)	70.7 ± 8.9	54.1 ± 7.0	62.4 ± 11.6

All values are based on the mean ± standard deviation, except for Participant

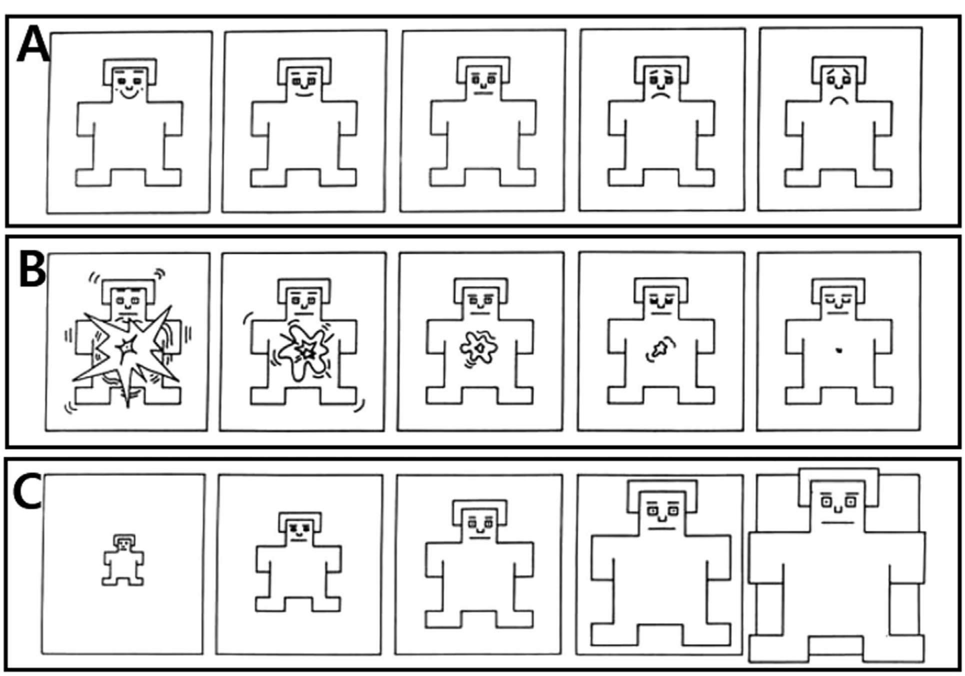

Fig. 2. Self-Assessment Manikin (SAM): A: valence, B: arousal, and C: dominance. The valence part assesses changes in the emotions of subjects based on a group of happy photographs compared with a group of unhappy photographs; the arousal part assesses changes in emotions based on excited compared with calm states; and the dominance part assesses changes in emotions based on controlled compared with uncontrolled states. The points increase from right to left.

Table 3
SAM data of each IAPS photographs.

Type of emotion	Number of photographs	Valence	Arousal	Dominance
Unhappy photograph group	1931	4.40 ± 1.33	3.20 ± 2.48	3.37 ± 2.86
	9410	2.20 ± 1.11	6.00 ± 2.18	4.50 ± 2.16
	3000	1.40 ± 0.76	7.00 ± 1.81	6.00 ± 2.52
	6350	2.67 ± 1.01	5.20 ± 2.14	4.53 ± 2.45
	3170	1.73 ± 0.89	6.60 ± 2.15	5.73 ± 2.48
	Total	2.48 ± 1.02	5.6 ± 2.15	4.83 ± 2.49
Happy photograph group	1931	6.40 ± 1.14	4.37 ± 2.24	2.67 ± 2.41
	9410	7.70 ± 1.24	3.90 ± 2.09	2.87 ± 2.38
	3000	6.00 ± 2.14	5.40 ± 2.14	3.90 ± 2.60
	6350	6.97 ± 1.35	5.07 ± 2.29	3.70 ± 2.40
	3170	7.20 ± 1.25	4.97 ± 2.42	3.40 ± 2.36
	Total	6.85 ± 1.43	4.74 ± 2.24	3.31 ± 2.43
Neutral photograph group	1931	4.50 ± 0.92	2.80 ± 2.17	2.50 ± 2.16
	9410	5.43 ± 1.15	1.77 ± 1.33	1.83 ± 2.09
	3000	4.30 ± 0.82	2.70 ± 1.53	2.30 ± 1.70
	6350	5.67 ± 1.12	2.03 ± 1.68	1.80 ± 1.78
	3170	5.20 ± 1.05	2.53 ± 1.84	2.37 ± 2.09
	Total	5.00 ± 1.01	2.37 ± 1.71	2.43 ± 1.96

Note: All values are based on the mean ± standard deviation.

Table 4
Correlation between RRI and SAM values in each photograph category.

	RRI in Unhappy group	RRI in Happy group	RRI in Neutral group
Arousal	−0.26	−0.20	−0.30
Valence	**0.32**†	−0.02	−0.27
Dominance	**−0.31**†	−0.18	−0.31
Integrated index	**0.32**†	−0.07	−0.20

† $p < 0.1$, SAM: Self-Assessment Manikin, RRI: R-R interval

of SAM. And a significant correlation (correlation: 0.32, P-value: 0.08) was observed only in the unhappy photograph group when using the integrated emotion index. The correlation between the integrated index and RRI was not significant in the happy or neutral groups (Table 4).

Although the correlation between arousal and RRI was not significant for photographs with an arousal value lower than 4.5 (correlation: −0.29, P-value: 0.11), it was significant for photographs with a arousal value over than 4.5 (correlation: −0.33, P-value: 0.08).

4. Discussion

Although many previous studies have used questionnaires to assess human emotions, this method has limitations because emotions can be expressed differently by individuals and cannot offer objective data. In addition, using subjective questionnaires allows the possibility that a subject may distort or unclearly express their feelings. Thus, assessing emotional changes with indexes that reflect physiological signals could be more objective and accurate than subjective reports. Although HRV would be a useful index for assessing human emotion since HRV reflects the autonomic nervous system, few studies have investigated the validity of HRV. This study is meaningful because it assessed the validity of HRV as objective tool for measuring human emotion.

Generally, emotion is assessed in terms of two factors (valence and arousal), with the valence value reflecting the direction of emotion and the arousal value reflecting the scope of emotional changes (Lang, 1995).

The RRI reactions to the SAM values in this experiment were observed only for the unhappy photograph group. Considering that the correlation between RRI and arousal score was significant only for photographs with a higher arousal score, the association between RRI and SAM might be significant when only emotional stimulation has a high arousal score. This observation showed that emotion was reflected in RRI only when the visual stimuli for emotional changes exceeded a certain SAM value (an arousal value of 4.5 based on the results of this study). Therefore, emotional stimuli of a certain minimum level should be used to measure reactions to emotional stimuli with HRV data.

There were some differences between the SAM values based on IAPS and those in this study. Although the valence scores from IAPS and this study were similar, the arousal score observed in this study was lower than that of IAPS. In the unhappy category, the arousal score was 7.12 ± 2.05 from IAPS and 5.6 ± 2.15 in this study. Additionally, in the happy category, the arousal value was 6.24 ± 2.05 from IAPS and 4.74 ± 2.24 in this study. This difference might be because of cultural differences. Ou et al. reported that four-color emotions were independent of culture across countries (Ou et al., 2004), and Lee et al. found little evidence of differences in response to the Likert scale format among the well-educated Japanese and Chinese respondents who made up their sample (Lee et al., 2002). Likewise, the subjects in this experiment were all Koreans, and they showed low arousal values for photographs in the happy and unhappy categories, unlike the SAM scores presented by the IAPS. Thus, further studies to develop visual stimuli while considering cultural context are needed.

This study investigated the validity of HRV as a tool to evaluate

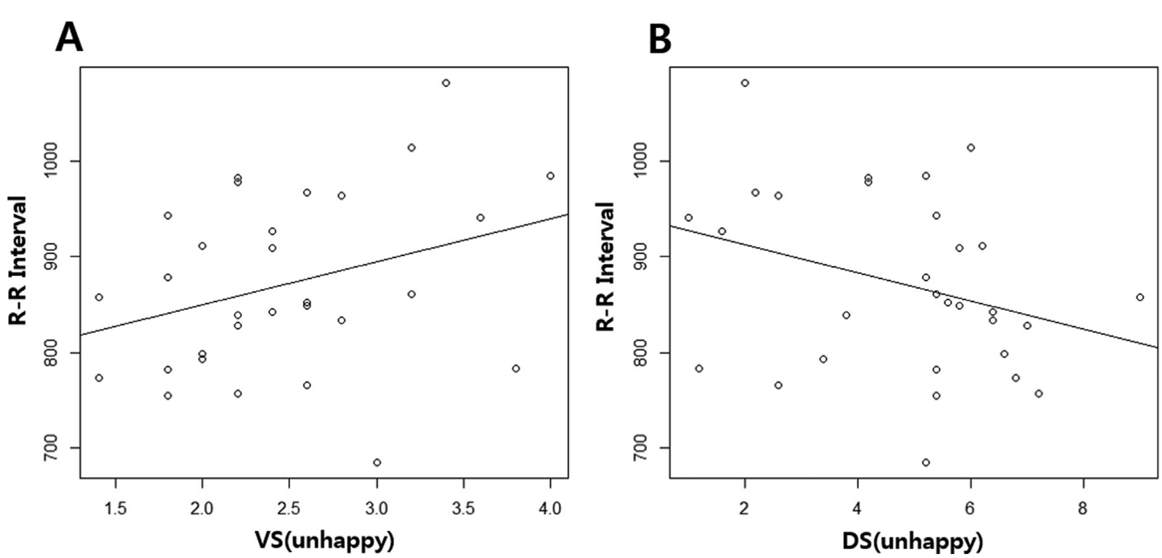

Fig. 4. SAM and RRI correlations with the unhappy category stimuli: A) correlation between valence and RRI and B) correlation between dominance and RRI.

human emotions. The results of this study showed that HRV could reflect human emotion only when emotional stimulation was relatively strong. Therefore, further studies assessing human emotion should use strong emotional stimulation, such as IAPS with a higher arousal value, and the intensity of the stimulation should be considered.

In this study, RRI was used as an index of HRV. RRI showed that heart rate interval and it could reflect autonomic nerve system. Autonomic nerve system control heart rate, and RRI could be changed when valence between sympathetic nerve and parasympathetic nerve was changed under emotion stimulation. Previous studies using HRV used LF/HF (Kop et al., 2011), standard deviation of the NN interval (SDNN) (Vaschillo et al., 2008), however, the proper index of HRV has not yet been determined. An appropriate index of HRV that shows changes in sympathetic nerves should be investigated in further studies.

This study verified a significant correlation between RRI and arousal score of SAM for photographs with a high arousal value. We recommend that photographs with high arousal values should be used in experiments using HRV to assess emotional changes.

Conflicts of interest

The authors declare that they have no competing interests.

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