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Jamalipournokandeh, Omid

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A Ubiquitous Healthcare System with the Integration of Psychological and Physiological Indices

17R8103 Omid Jamalipournokandeh
Supervisor: Kazuo Yana

Abstract— The importance of the role of persistent daily healthcare monitoring has been widely recognized in order to tackle stress and variety of psychological disorders. This research study examined if three psychological states such as *Flow Frequency*, *Resilience and Self-Esteem* out of five, could be determined by physiological indices. We specified four key parameters as diurnal heart rate rhythm for *Double Cosinor* and *Spline Smoothing* methods, i.e. 24-hour Rhythm Amplitude (A_{24}), 12-hour Rhythm Amplitude (A_{12}), Combined Rhythm Amplitude (A) and Autonomic Switching Rate (ASR). For these parameters, mean and median values were assessed and their relationship with the psychological experiences were fully analyzed to find appropriate correlations. As a result, cA_24 and sASR ($R^2=0.5088$, $\lambda<0.05$) are highly correlated with the *Flow Frequency* index in the heart rate rhythm analysis. For the *Resilience* case, the pair of cA and sASR* ($R^2=0.3101$, $\lambda<0.05$) are correlated. Finally, cA* and cASR* ($R^2=0.3003$, $\lambda<0.05$) are correlated with the psychological state, *Self-Esteem*. This finding is important to evaluate the mental wellness of individuals as well as developing a reliable healthcare system.

Keywords— Ubiquitous Health Care, Positive Psychology, Flow Experience, Heart Rate Variabilities

I. INTRODUCTION

This research propounds a ubiquitous healthcare system that regularly monitors the mental state of individuals with the aid of psychological and physiological rhythm indices. Nowadays, the IoT technology (Internet of Things) has become popular and cloud-based services are widely spreading [1]. Along with this, the significance of wearable devices has been understood as these systems are able to routinely obtain everyone's biomedical signal such as heart rate data, number of steps, sleep stages, calories and transmitting these data to the cloud in order to automatically grasp individual's mental soundness. In recent years, due to the complexity of social environments and the increased progression of stress with advanced technology, people are constantly failing to maintain the balance between their physical and mental states. In the field of healthcare, a lot of attention has been focused on the healthy life expectancy instead of just the life itself. To keep individuals' wellness is crucial in the aged society as it is important to be healthy both physically and mentally. According to the survey by the Ministry of Health, Labor and welfare in Japan, 59.5% of Japanese workers were suffering from strong mental stress, which illustrates 3.8-point increase from the previous report [2]. Usually, the main causes of stress are family problems, heavy workload and the demand for high quality of labor. In many situations, the increased amount of stress leads to suicide which is a major problem these days. In fact, the number of suicides per year over the past decade is still over 20,000 despite having a declining trend [2]. Having such statistics, the importance of mental healthcare monitoring is realized these days, and it finally brought our attention to develop a healthcare system in order to help people who are suffering from mental disorders. The system requires two inputs: psychological indices and physiological indices. Gathering these crucial parameters allows us to evaluate the mental wellness of individuals. For analysis, psychological states such as Self-Efficacy and Anxiety were excluded since the correlations of these psychological states were not high with physiological parameters.

II. METHODS

A. Psychological Indices

Psychological experiences quantify the subject's daily mental state. They are evaluated based on a questionnaire which is conducted by a psychologist. We are evaluating the following three indices:

- *Flow Frequency*

Flow is the mental state in which individuals are extremely involved in a certain activity, feeling so energized and enthusiastic. *Flow Frequency* has been quantified to appraise mental healthiness and can be measured based on a questionnaire. There are 4 questions, which are basically focusing on the type of the activity, its uniqueness and worthiness, the time of doing it and the experiences the person had when doing the activity during that period. Questions are leveled on a 7-point rating from 1 (few times annually) to 7 (few times a day). The final score is 28 [3]. Fig 1. demonstrates the concept of *Flow* where boredom and anxiety are on either side of the *Flow* channel. If challenge is very high for the required skill level, anxiety will occur. If it's very simple, boredom will happen. When individuals have high skill for an activity, they feel relaxed. However, to reach the *Flow* state, both skill and challenge must be balanced at high level. At this stage, people think the time is passing quickly because the activity absorbed all attention.

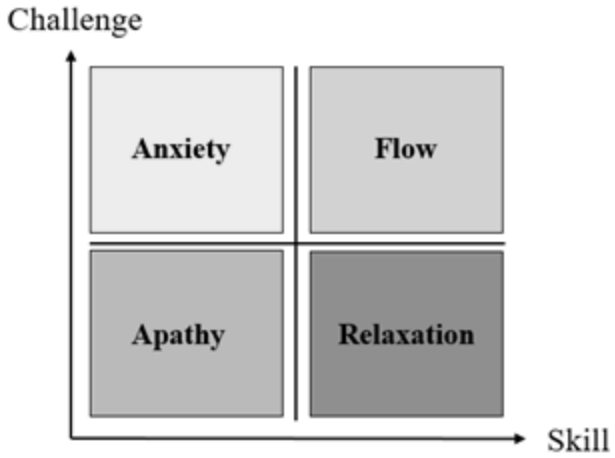

Fig 1. Experiencing the *Flow* based on skill and challenge

- *Resilience*

The next psychological characteristic called *Resilience* is the extent of how well people are recovered from the occurrence of mentally stressful events. This occurs in individuals who improve psychological and behavioral abilities that let them remain peaceful during hardships and to move on from the event without long-term negative outcomes. *Resilience* is an evolutionary phenomenon that people use to manage stressors. 21 questions on a 5-point rating from 1 (not at all) to 5 (always) are divided into three main categories: 7 questions related to the tendency of pursuing new things, 9 for controlling emotions and 5 for the positive foreseeing tendency. The total score is from 21 to 105 [3]. According to Fig 2. when the stressor occurs, in person's meta-awareness section which is responsible for dealing with challenges, if person is resilient, some *Resilience* related factors such as confidence, positive personality, focus and motivation will affect that stressor. As a result, that person will be able to avoid the stressor by thinking about positive things which later leads to having boosted responses as well as a good overall performance.

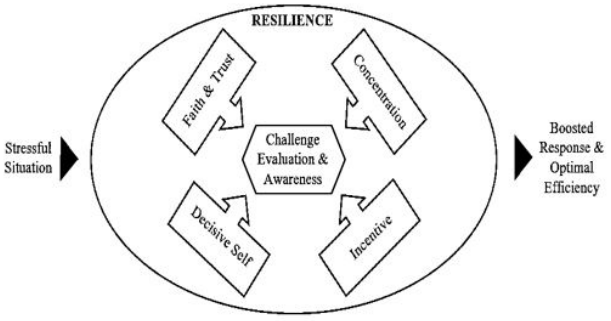

Fig 2. A model for *Resilience* and its characteristics to deal with stressors and improving the overall performance

- *Self-Esteem*

The last psychological state is *Self-Esteem*. The degree in which a person feels confident, honorable and noteworthy. It is be viewed as a scale of how much individuals appreciate and value themselves. Individuals with high *Self-Esteem* often feel nice about themselves and think about their achievements during life. On the other hand, people with low *Self-Esteem* often feel embarrassed, are easily troubled with failure and have doubt about themselves. 10 questions on a 5-point rating from 1 (not actually the case) to 5 (completely true), asking individuals about their overall belief on themselves. The total score is from 10 to 50 [3]. Fig. 3 emphasizes on the fact that when propounding *Self-Esteem*, it is essential to note that both high and low levels can be detrimental for the individual in terms of sociality and emotion. Veritably it is believed an optimum level of *Self-Esteem* sits in the middle. People who are functioning within this range are more socially prevailing.

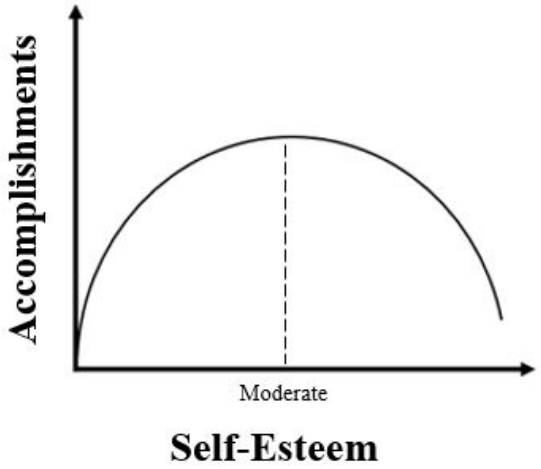

Fig 3. Curvilineal paradigm of *Self-Esteem*

B. Physiological Indices

Physiological indices are objective based, and they are the main input for our healthcare system. They are measured through biomedical signals taken by a wearable technology or a Holter electrocardiogram device [4].

- *Double Cosinor Method*

The Double Cosinor method [5] was applied to the heart rate data continuously recorded in every 1 minute by a wrist device. The heart rate sequence obtained by the wrist device over a day is fitted by two sinusoids in Eq. (1):

$$H(t) = M + A_{24}\cos\left(2\pi\frac{1}{T_{24}}(t-t_{24})\right) + A_{12}\cos\left(2\pi\frac{1}{T_{12}}(t-t_{12})\right) \quad (1)$$

Here, M is the average heart rate, A_{24} and A_{12} are 24-hour and 12-hour amplitude of the heart rate diurnal rhythm

respectively. Expressions inside the parenthesis are corresponding phases. The parameters are estimated by the least square method to minimize the residual variance. A typical example of fitted Cosinor curve is shown in Fig. 4. It is noted that the major trend component in the heart rate sequence is fitted well by the Cosinor curve. The additional harmonic components showed no significant improvement in the residual variances.

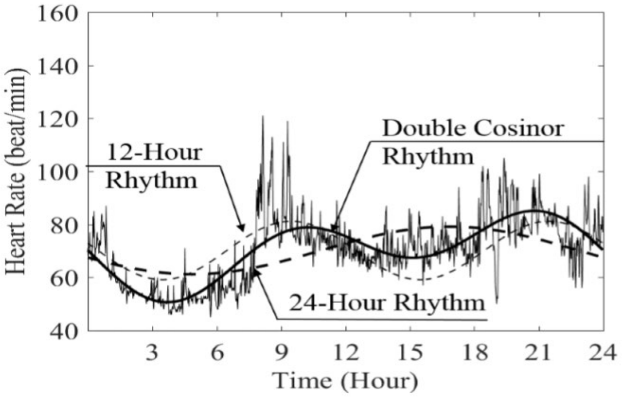

Fig 4. A typical Cosinor curve fitting of the heart rate sequence in one-minute interval

Eight parameters are extracted from the heart rate data. There are 4 mean parameters: 24-hour, 12-hour, combined Cosinor rhythm amplitude (cA_24, cA_12 and cA), and the newly defined index called the autonomic switching rate (ASR). It's the rate of autonomic activity from sleep to wake state transition. As a result, cASR is defined as the maximum value of the derivative of the combined Cosinor rhythm [6-7]. In addition, we have 4 median parameters such as cA_24*, cA_12*, cA* and cASR*.

- *Spline Smoothing Method*

Spline smoothed heart rate signal *s(t)* is obtainable by minimizing the following Eq. (2):

$$(1-\lambda)\sum_{n}(s(n\Delta t)-hr[n])^2+\lambda\int\left(\frac{d^2s(t)}{dt^2}\right)^2 dt \quad (2)$$

Based on the equation, the time series *hr[n], n = 1, … ,1440* defines the measured heart rate in each one-minute intervals. The smoothing parameter λ takes values from 0 to 1 specifying the smoothness of the Spline function. When $\lambda=0$, the Spline function *s(t)* roughly tracks the sampled heart rate values *hr[n]* 's, i.e. Note that *s(t)* is the interpolated heart rate signal. As λ approaches to one, smoothness plays a significant role. A typical example of interpolated Spline curve is shown in Fig. 5 where the Spline curve tends to pursue the Cosinor curve with respect to the appropriate $\lambda=0.002$.

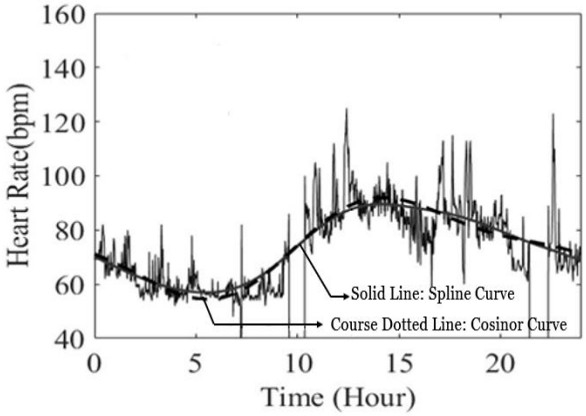

Fig 5. A typical Spline curve fitting of the heart rate sequence in one-minute interval

The second step of the Spline interpolation-based method is to apply the Fourier series expansion to the Spline smoothed heart rate signals. The expansion yields the same parameters obtained from the Cosinor method. The parameters are differentiated from those derived from Cosinor method by adding prefix "s" instead of "c" at the beginning of the notation, e.g. sASR instead of cASR.

III. RESULTS

20 healthy employees (11 males, 9 females) from a software and information technology company (*ISID_AO Co. Ltd., Tokyo, Japan*) recorded their heart rate daily for approximately one month (4 weeks) through a wrist device (*Fitbit Charge II, Fitbit, Inc.*). Only the weekday data were used for the analysis. Fig. 6, Fig. 7 and Fig. 8 show the multiple regression analysis of the three psychological indices. For the *Flow Frequency* case, 4 subjects were excluded. The technique demonstrated a good correlation ($R^2=0.5088$, $\lambda<0.05$) for *Flow Frequency*, ($R^2=0.3101$, $\lambda<0.05$) for *Resilience* and ($R^2=0.3003$, $\lambda<0.05$) for *Self-Esteem.* The Spline smoothing parameter is the key to balance the smoothness and the goodness of fit has been used to increase the correlation.

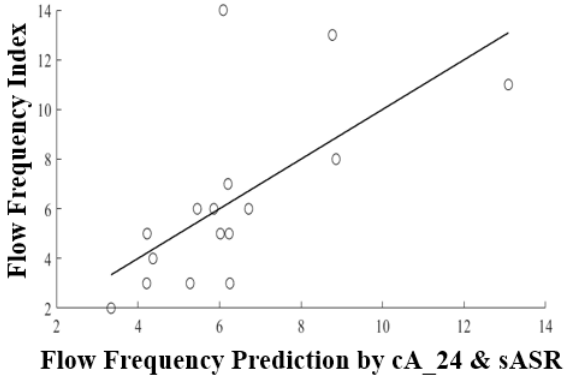

Fig 6. Relationship between *Flow Frequency* & (*cA, sASR*)

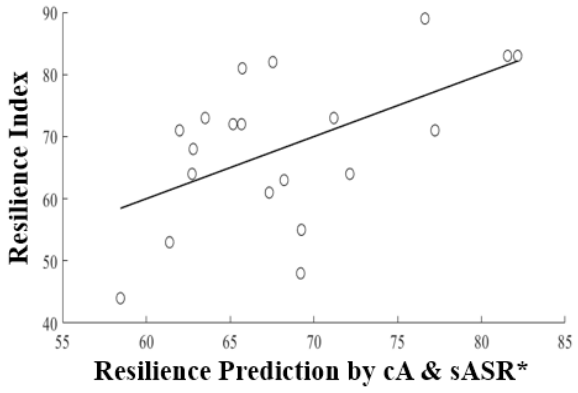

Fig 7. Relationship between *Resilience* & (*cA, sASR**)

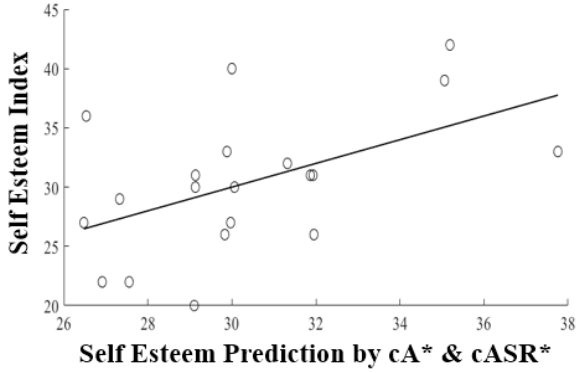

Fig 8. Relationship between *Self-Esteem* & (*cA*, cASR**)

Table.1, Table.2 and Table.3 illustrate the results of classification accuracy for the three psychological indices with their associated physiological parameters that showed the highest correlation.
(A: Accuracy, ER: Error Rate, P: Precision, S: Sensitivity, SP: Specificity, FPR: False Positive Rate, TPR: True Positive Rate and FNR: False Negative Rate)

Table 1. Performance of *Flow Frequency* & (cA, sASR*)

A	ER	P	S	SP	FPR	TPR	FNR
0.88	0.13	1.00	0.60	1.00	0.00	0.60	0.40

Table 2. Performance of *Resilience* & (cA, sASR*)

A	ER	P	S	SP	FPR	TPR	FNR
0.70	0.30	0.57	1.00	0.50	0.50	1.00	0.00

Table 3. Performance of *Self-Esteem* & (cA*, cASR*)

A	ER	P	S	SP	FPR	TPR	FNR
0.75	0.25	0.86	0.60	0.90	0.10	0.60	0.40

IV Conclusion

In order to aid in developing and managing a ubiquitous healthcare system, we examined the relationship between three psychological experiences such as *Flow Frequency*, *Resilience* and *Self-Esteem* along with heart rate rhythm parameters. The results suggest that there is a fairly strong correlation between physiological and psychological indices that represent the reactivity of autonomic nervous system. Therefore, it is possible to evaluate psychological experiences through heart rate rhythm parameters. Combination of such indices will be a leading factor to comprehend the development of credible mental healthcare system. As a future work, since the number of samples was quite small, we must perform this operation again for a large number of subjects to make sure that our result was not based on chance. Furthermore, we need to perform extensive research on how to improve the correlation with other remaining psychological indices such as *Self-Efficacy* and *Anxiety*.

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