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A novel method of evaluating changes in intrinsic motivation during cognitive rehabilitation

Y. Nishiwaki, *Student Member*, M. Nakamura, M. Nihei, *Member, IEEE*

***Abstract*— Motivation is one of the most important affecting rehabilitation outcomes. In present study, we propose a novel method to evaluate intrinsic motivation. We conducted experiments of simulated cognitive rehabilitation exercises. The results of these experiments demonstrate that intrinsic motivation is correlated to valence. Furthermore, CIM (Changes in intrinsic motivation) can be detected with up to 80% accuracy, using physiological states. The result showed that this method more precisely detects CIM than occupational therapists.**

***Clinical Relevance*—The proposed method enables to evaluate changes in intrinsic motivation during cognitive rehabilitation without disturbing or suspending rehabilitation.**

I. Introduction

Motivation is considered one of the most important determinants of rehabilitation outcomes, such as adherence, accuracy, and execution duration [1,2]. During in-home rehabilitation, it is often difficult for patients to maintain their motivation, due to lack of social interactions or continuous care from therapists, and they eventually become bedridden and housebound [3]. Specifically, during cognitive rehabilitation, functional recovery is obscure, and it is therefore particularly difficult for patients to maintain their motivation, compared to physical rehabilitation [4]. Therapists typically encourage patient tasks according to their motivation, as evaluated through facial expressions and behaviors [5]. However, motivation, internal cognitive phenomena, cannot be sufficiently evaluated through external movements. A method of evaluating motivation during rehabilitation is needed, especially for cognitive rehabilitation in which motivation cannot be easily assessed by patients' action.

A model using occurrences of human behavior has been previously supported by psychological research. The model consists of six factors, as follows: stimulations, emotions, physiological states, motivations, behaviors, and consequences of behaviors. According to the model, stimulations from the surrounding environment generate emotions, and these motivate behavior. It also predicts that physiological reactions arising from behaviors serve as motivators for subsequent behaviors. Therefore, we hypothesize that motivations, emotions, and physiological reactions are correlated, and clarification of their relationship will enable changes in motivation to be evaluated during rehabilitation, using internal movements or physiological states.

Motivation produces arousal, direction, and persistence of behaviors [6]. There are three types of motivation: intrinsic motivation (IM), extrinsic motivation (EX), and motivation [7]. People with high IM tend to participate in their rehabilitation more continuously and precisely compared to high EX [8-10]. Moreover, previous research has found that an increase in EX undermines IM and leads to an overall decrease in motivation [11]. In this study, we focus on IM.

In the present study, we propose a novel method for evaluating changes in intrinsic motivation (CIM) during cognitive rehabilitation, using physiological states, which enables therapists to determine whether a patient's IM is increasing or decreasing. First, we conducted an experiment to determine the relationship between IM and emotions. From that relationship and the relationships between emotion and physiological states, we extracted potential physiological states, which are hypothetically related to IM. Then, we designed the evaluation method based on these potential physiological states, and its validity and effectiveness were verified.

II. Experiment 1

An experiment was conducted to clarify the relationship between IM and emotion.

A. Methods

Six healthy men (22-24 years of age) participated in this experiment. They were instructed to conduct two self-examinations: Trail Making Test B (TMT-B) and a subtask of the Continuous Attention Test (CAT) [12]. The Symbol digit Modalities Test (SDMT) and the Visual Cancellation Task (VCT) were selected from the CAT. The average duration of each trial was approximately 1min, and each trial was conducted 10 times. At the end of each test session, participants were instructed to complete two subjective scales: The Intrinsic Motivation Inventory (IMI) and the self-Assessment Manikin (SAM) [13-14]. All participants completed 20 trial each, resulting in 120 sets of IMI and SAM data being collected. All experiments were conducted following approval by the University of Tokyo for Life Science Research Ethics and Safety (No. 15-187).

B. Results

The relationship between IM (IMI) and valence (SAM, valence) scores are shown in Fig. 1. The results demonstrate that Pearson's Product-Moment Correlation reveal

Y. Nishiwaki, M. Nakamura, and M. Nihei* is with The University of Tokyo, Chiba, Kashiwa 5-1-5 Japan (*corresponding author to provide phone: +81-80-3576-3025; fax: +81-4-7136-4666; e-mail: mnihei@edu.k.u-tokyo.ac.jp) (7540487034@edu.k.7540487034@edu.k.u-tokyo.ac.jp, nakamura.mio@edu.k.u-tokyo.ac.jp)

ed a strong positive correlation between IM and valence (r = 0.83).

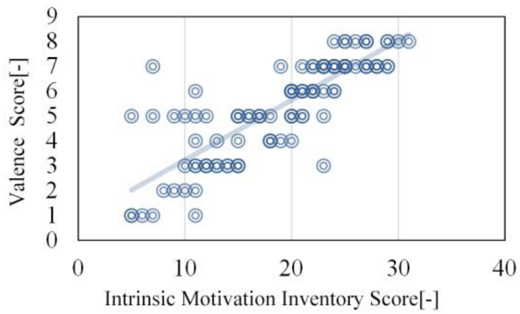

Figure 1. Relationship between intrinsic motivation and valence. The approximation straight line is an asymptote. IMI = Intrinsic Motivation Inventory

The relationships between IM (IMI) and arousal (SAM, arousal) can be categorized into two groups (α, β), as shown in Fig. 2 and Fig. 3, respectively. In group α, shown in Fig. 2, there is a strong positive correlation between IM and arousal (r = 0.76). On the other hand, in group β, the relationship between IM and arousal is described by a downward protruded quadratic curve.

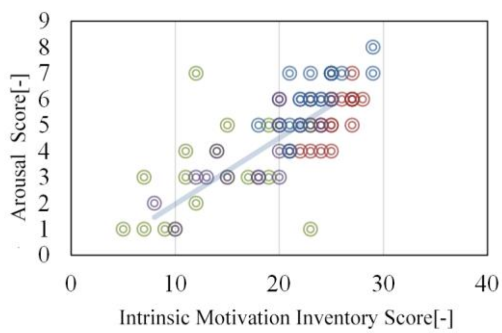

Figure 2. Relationship between intrinsic motivation and arousal (α). Colors indicate the values for each participant. IMI = Intrinsic Motivation Inventory

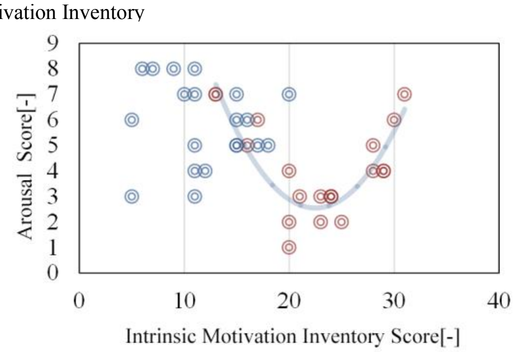

Figure 3. Relationship between intrinsic motivation and arousal (β). Colors indicate the values for each participant. IMI = Intrinsic Motivation Inventory

C. Discussion

Outliers from the asymptote in Fig. 1 primarily resulted from one participant; debriefing after the experiment revealed that some emotional states resulted from the testing environment rather than from the task. Therefore, we considered that the results from this participant were unrelated to the relationship between IM and valence and recalculated the correlation excluding these results (r = 0.94)

The strong correlation between IM and valence indicates that pleasantness generates IM for a behavior, and IM can be measured by valence. Regarding the relationship between IM and arousal, the differences between the two groups result from differences in emotions related to the experiments, which can be determined by the valence and arousal SAM scores. In both group, participants were excited when IM was high, and felt bored when IM was low. However, arousal scores were high when IM was low in group β; therefore, participants in this group were angry or irritated by the experimental tasks when IM was low.

III. Experiment 2

Based on the results of experiment 1, we hypothesized that IM can be revealed by the physiological states used to determine valence. Since the proposed IM evaluation method is intended for applications in rehabilitation hospitals or in-home rehabilitation, the physiological states used for this system must be detected in those situations and also not disturb or suspend rehabilitation. we selected three physiological states related to valence, which can be detected in actual rehabilitation situations, as follows: heart rate variability (HRV), heart rate (HR), and fingertip skin-surface temperature (FST). HRV reflects sympathetic neural activities and relate to valence [15-16]. HR is with variation depending on physiology (valence and arousal) and factors such as age, physical strength, and health status. FST changes depending on the amount and distribution of blood flow, and reportedly decreases as valence decreases [17].

Based on the physiological states determined in the previous experiment, a method for evaluating CIM is proposed. This method evaluates IM every minute, which is sufficient to enable therapists and caregivers to maintain high IM in patients.

A. Methods

Fifteen healthy men (22–32 years of age) voluntarily participated in this experiment.

Participants were asked to get a good night's sleep the night before the experiment, and were asked to refrain from ingesting drugs and caffeine on the day of the experiment. the participants were instructed to conduct a self-examination of their attention for three 10 min sets (30 min in total). the Continuous Performance Test (CPT), from a subtask of the CAT, was used. The CPT includes a display of random numbers (1–9) that appear on a screen at 1–2 s intervals. There were sufficient breaks between sets for participants to recover from the stress or other mental changes produced by the self-examinations. The experiment was conducted in a sitting position, and in a quiet environment. The experimental timeline is shown in Fig. 4.

Physiological states were measured during the experiment. In order to detect CIM, participants were instructed to raise or lower their left hand when they felt their IM significantly increase or decrease, respectively.

FST was measured at 0.5 Hz, using a hand thermometer (LT-8 Gram Corporation, Saitama, Japan), with the electrode attached to the tip of the participant's index finger. HRV and HR were calculated from electrocardiograms (ECGs) measured by a single sensor (WEB-7000, ECG picker, NIHON KOHDEN Ltd., Tokyo, Japan). ECGs was measured at 10 Hz, using electrodes attached to the participant's chest.

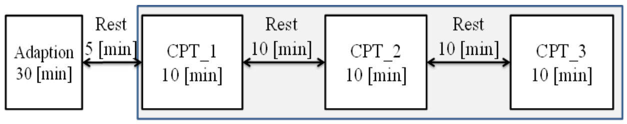

Figure 4. Experimental timeline. CPT=Continuous Performance Test

B. Data collection and Analysis

HR and HVR were calculated by measuring the interval between consecutive R waves (R-R interval; RRI), and RRI was calculated from ECG. Five aspects of HR (maximum, minimum, change, standard deviation, and mean) are typically assessed [18-19]. Since the only HR variable is RRI, it was used in the present experiment. HRV is analyzed by calculating the powers of the low-frequency (LF: 0.04–0.15 Hz) and high-frequency (HF: 0.15–0.4 Hz). LF and HF are standardized as:

$$\text{LFstandardized} = \frac{LF}{LF+HF} \quad (1)$$

$$\text{HFstandardized} = \frac{HF}{LF+HF} \quad (2)$$

The selected physiological indicators included 11 items; LF, HF, LF/HF, $LF_{standardized}$, $HF_{standardized}$, RRI_{max}, RRI_{min}, RRI_{ver}, RRI_{dev}, RRI_{ave}, and mean FST. All of them were measured or calculated at 1min before and after CIM. Since 1min CIM are short periods of time for HRV analysis, the maximum entropy method (MEM) was used for the frequency analysis.

Using the above values at 1 min before and 1 min after CIM, the absolute values at 1 min before and 1 min after CIM, the variation in positive/ negative values at 1 min before and 1 min after CIM during 11 physiological indices (44 variables) is explained, as shown in Table 1.

TABLE I. EXPLANATION OF VARIABLES

Name of variables	Definition
(index)_before	Value of index 1 min before CIM
(index)_after	Value of index 1 min after CIM
(index)_difference	Variation in absolute value (| y |) of index 1 min before and after CIM
(index)_PN	Variation in the positive/ negative value (y = positive/ negative) of index 1 min before and after CIM

Logistic regression analyses were used to determine a method to assess whether patient motivation is changing. Increases and decreases in CIM were the outcome variables. The 11 variables described above were assessed as potential predictor variables. A stepwise selection method was used to identify variables for inclusion in the regression model, and the p-value cut-offs were 0.1, 0.2, and 0.3.

C. Results and Discussion

CIM was measured 137 times (UP: 45 times, DOWN: 92 times). The linear combinations of the predictor variables were termed motivation equation I (p = 0.1), motivation equation II (p = 0.2), and motivation equation III (p = 0.3). Table 2 shows the variables selected by the equation models, using the logistic regression analyses and the accuracy rate of the models, which are categorized by the p-value cutoff.

$$equation\ I = logit(y) = 1.131\alpha_1 - 1.237 \quad (3)$$

where, y is IM up (1)/down (0), $\alpha 1$ HF_PN.

$$equation\ II = logit(y) = 1.1477\beta_1 - 0.300\beta_2 + 0.228\beta_3 - 1.198 \quad (5)$$

where, y is IM up (1)/down (0), β_1 is HF_PN, β_2 is LFHF_before, β_3 is LFHF_difference.

$$equation\ III = logit(y) = -0.064\gamma_1 + 0.109\gamma_2 - 0.165\gamma_3 + 0.051\gamma_4 - 1.694\gamma_5 - 0.570\gamma_6 + 0.177\gamma_7 - 18.422\gamma_8 - 8.446\gamma_9 - 0.023\gamma_{10} + 0.014\gamma_{11} - 0.788\gamma_{12} - 0.017\gamma_{13} + 0.004\gamma_{14} + 0.002\gamma_{15} + 0.019\gamma_{16} - 1.430\gamma_{17} + 1.852\gamma_{18} - 1.721\gamma_{19} + 1.941\gamma_{20} + 1.073\gamma_{21} + 13.78 \quad (6)$$

where, y is IM up (1)/down (0), γ_1 is LF_before, γ_2 is LF_after, γ_3 is HF_after, γ_4 is HF_difference, γ_5 is HF_PN, γ_6 is LFHF_before, γ_7 is LFHF_difference, γ_8 is $LF_{normalized}$_after, γ_9 is $HF_{normalized}$_before, γ_{10} is RRI_{max}_before, γ_{11} is RRI_{max}_difference, γ_{12} is $Rie_{man}n$, γ_{13} is RRI_{var}_difference, γ_{14} is RRI_{dev}_before, γ_{15} is RRI_{dev}_difference, γ_{16} is RRI_{ave}_after, γ_{17} is RRI_{ave}_PN, γ_{18} is FST_before, γ_{19} is FST_after, γ_{20} is FST_difference, γ_{21} is FST_PN.

TABLE II. EXPLANATION OF VARIABLES

p-value cutoff	Selected variable types		Accuracy rate
0.1	HF		65.0%
0.2	HF	LF/HF	70.1%
0.3	All 11 variables		80.3%

Table 2 demonstrates that CIM can be measured with accuracy as high as 80.3%, by measuring certain physiological states. Moreover, HF, which appears to reflect parasympathetic neural activity, is selected as a predictor in every equation. Therefore, the findings support that parasympathetic neural activity has a dominant impact on CIM. Furthermore, pleasantness arising from relaxation and unpleasantness arising from stress are critical emotions related to CIM [20].

IV. EXPERIMENT 3

To verify the validity of the proposed equations as the bases for a 1 min evaluation of CIM, the three equations were assessed in other participants conducting self-examinations of their attention. In addition, to verify the effectiveness during actual rehabilitation, our novel method of evaluation was compared with evaluations by occupational therapists who work at rehabilitation hospitals.

A. Methods

Four healthy men (23–24 years of age) voluntarily participated in this experiment.

Participants were asked to get a good night's sleep the night before the experiment, and were asked to refrain from ingesting drugs and caffeine on the day of the experiment. During the experiment, participants were instructed to complete 20 self-examinations of their attention, for 20 min. The TMT-B and VCT, which were also used in experiment 2, were used. The experimental timeline is shown in Fig. 5.

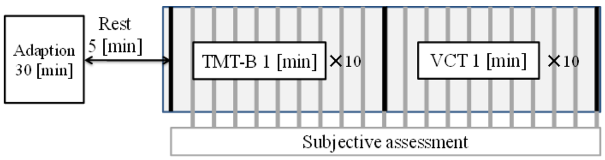

Figure 5. Timeline of the verification experiment. TMT-B = Trail Making Test B; VCT = Visual Cancellation Task

To evaluate CIM, participants were instructed to stop each examination after 1 min, regardless of whether it was finished or not, and to complete an IMI. Physiological states were measured using the same apparatus and methods used in experiment 2. To compare our novel method with evaluations by therapists, five occupational therapists (OTRs) who had worked at rehabilitation hospitals for 6–16 years (28–42 years of age; two men and three women) were recruited and instructed to evaluate participant motivation. Evaluations of motivation by the therapists were also measured by the IMI. Two or three of the OTRs were seated in an area separate from the participants, which allowed observation using a one-way mirror to avoid the therapists affecting participant motivation (Fig. 6).

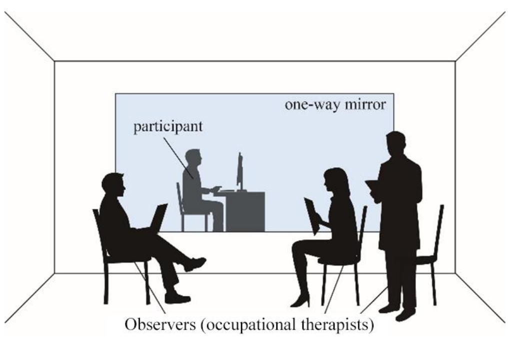

Figure 6. Experimental setup.

C. Analysis

CIM were measured by evaluating whether the IMI scores increased or decreased. CIM were also predicted by assessing the measured physiological data using the proposed motivation equations, and accuracy was calculated by comparing participant CIM.

To verify the validity of CIM, the significance of the predicted CIM by the proposed method was calculated using a chi-squared goodness of fit test.

To verify the effectiveness of CIM, the predicted CIM by the OTRs were also assessed with the IMI, and accuracy was calculated by comparison to participant CIM.

D. Results

The accuracy rate of the proposed motivation evaluation equations (Equations I, II, III) were 55.1%, 68.2%, and 65.2%, respectively. Furthermore, the results of the chi-squared goodness of fit test, support the validity of Equations II and III [$\chi 2(1, N = 4) = 0.008$; $\chi 2(1, N = 4) = 0.017$]. When only the significant CIM (|change in IMI score ≥3) were extracted, the accuracy rates for Equation II' and III' are 68.8% and 77.1%, respectively. Therefore, the evidence supports that these two equations have stronger predictive power when the CIM are larger.

Validation of effectiveness (the proposed evaluation estimate) or CIM, was estimated to be similar or better, compared to the five OTRs. The OTRs evaluated IM 200 times, which represents IMI changes 20 times for each two participants. With the exception of when there was no change in IMI scores, CIM was verified 149 times. The correct answer rate for the IMI evaluation by the OTRs was 43.8–63.5%.

The average accuracy of the therapists' ratings was 56.2 ± 8.6%, as shown in Fig. 7. Compared to the accuracy of the proposed IM evaluation equations, motivation equations II and III are considered to be effective in actual rehabilitation, as their accuracy rates exceed that of the therapists; therefore, our proposed evaluation method may be more useful than a therapist regarding CIM evaluations.

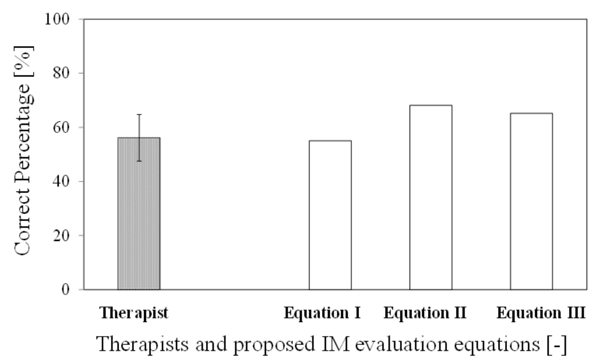

Figure 7. Comparisons of evaluations by therapists and by the proposed intrinsic motivation (IM) equations.

E. Discussion

Our results demonstrate that equations II and III of the proposed IM evaluation index adequately predict CIM. In particular, large CIM evaluations are most accurately predicted.

In addition, CIM estimations of differences in the correct answer rate occurred between UP and DOWN changes. For example, for equation II, there was an 80.5% accuracy rate when the IM was DOWN, whereas it was 50.5% for UP. This finding enables an accurate perception of reduced motivation, thereby enabling timely intervention and actions that are suitable for evaluating motivation during rehabilitation.

Furthermore, the present results demonstrate that the average IM evaluation was excellent, with approximately 64% accuracy; this accuracy rate was better than that of OTRs with a mean clinical experience of 10 years. Our findings indicate limitations in the accuracy of evaluation of a patient's motivation when evaluated solely by observations during therapy by experienced practitioners. Therefore, the presently proposed method to estimate CIM would be a useful addition to clinical practice by OTRs.

The experiments in this paper were conducted using healthy young men, and performance was assessed using cognitive tests. Further research is therefore needed to enable generalization of the proposed method to women, other age groups, and people with disabilities. In addition, the small sample size and narrow range of participant's age are the limitation of this study, hence it is necessary to increase the number of participants. Such expansion of the present experiments may result in inclusion of other physiological movements. Moreover, experiments assessing other tasks should be conducted to determine whether the present method can be applied to other tasks, such as physical training.

V. Conclusion

We conducted three different experiments, focusing on the relationships between IM, emotions, and physiological states, in order to propose a novel method of evaluating IM during rehabilitation. We found a significant relationship between IM and valence, which is pleasantness in emotion ($r = 0.83$). Moreover, a method of evaluating CIM was proposed, using three equations; two of the equations were valid and effective for predicting CIM, with an 80.3% accuracy rate. HF, which reflects parasympathetic nervous system activity, was the only selected predictor variable in both equations; therefore, it is presumable that parasympathetic nervous system activity has a significant impact on IM. Therefore, activating the parasympathetic nervous system, such as by inducing relaxation, may contribute to maintaining high levels of IM. The proposed evaluation method for CIM, using two valid equations, is effective in actual rehabilitation when compared to evaluations made by therapists.

To extend the use of our novel method, it must be applied to patients in rehabilitation hospitals and in other rehabilitation contexts, such as physical training. In addition, to improve the accuracy of our method, the characteristics of each physiological state should also be considered, as the typical reaction times differ between physiological states. Moreover, the present research focused on subjective self-examinations to propose a novel method of evaluating CIM. Thus, the accuracy rate may be improved by incorporating data from externally recognizable reactions, such as facial expressions and behaviors.

The method proposed in this study could detect CIM with up to 80% accuracy, which is higher than that by occupational therapists under limited conditions assuming cognitive rehabilitation. This suggests the possibility of the objective evaluation of intrinsic motivation, which could only be subjectively evaluated so far.

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References

[1] Chan DK, Lonsdale C, Ho PY Yung PS, Chan KM, Patient Motivation and Adherence to Postsurgery Rehabilitation Exercise Recommendation: The Influence of Physiotherapists' Autonomu-Supportive Behaviors, Arch Phys Med Rehabil, Vol.90, pp.1977-82, 2009.

[2] Choi KH, Fiszdon JM, Bell MD, Beyond Cognition: A Longitudinal Investigation of the Role of Motivation During a Vocational Rehabilitation Program, Journal of Nervous & Mental Disease, Vol. 201, No. 3, pp.173-178, 2013.

[3] Takao I, Roles of Physical Therapists in the Home-Based Rehabiliation, Rigakuryoho Kagaku, Vol. 17, No. 4, pp. 215-220, 2002 (in Japanese).

[4] Noboru H, Relationship of subjective and physiological responses of locomotion, The 27th Annual Conference of the Japanese Society for Artificial Intelligence, 2013 (in Japanese).

[5] Kibayashi M, The Influence of Care Workers' Speech Manner the Vitality of the Elderly, Journal of Shizuoka University, Vol. 21, 2007 (in Japanese)

[6] Robert EF, Human Motivation, Wadsworth Publishing Company; 6th Revised, 2006.

[7] Edward D, Richard M.R, Intrinsic motivation and self-determination in human behavior, New York: Plenum, 1985.

[8] Saperstein AM, Fiszdon JM, Bell MD, Intrinsic Motivation as a Predictor of Work Outcome After Vocational Rehabilitation in schizophrenia, J Nerv Ment Dis. Sep; 199(9): 672-7, 2011.

[9] Roberto C, Fabrizio P, Alessandra M, carmen D, Silvestro M, Chiara MC, et. al, Design Strategies to improve patient motivation during robot-aided rehabilitation, J Neuroengineering Rehabil., 4:3, 2007.

[10] Hooman S, Mohsen S, Nasrollah A, Motivational factors of adherence to cardiac rehabilitation, Iran J Nurs Midwifery Re, 17(4): 318-324, 2012.

[11] Edward LD, Intrinsic Motivation. New York: Plenum Press. 1975.

[12] Tom NT, Trail Making Test A and B: Normative data stratified by age and education, National Academy of Neuropsychology, 2003.

[13] Intrinsic Motivation Inventory (IMI) http://www.selfdeterminationtheory. org/intrinsic-motivation-inventory/ (accessed 30 January 2015).

[14] Lang PJ, Behavioral treatment and bio-behavioral assessment: computer applications, Technology in mental health care delivery systems, pp. 119-137, 1980.

[15] Sadaf M, Shahab R, Nader JD, Saman P, Study of Induced Emotion by Color Stimuli: Power Spectrum Analysis of Heart Rate Variability, Computing in Cardiology, pp. 977-980, 2014.

[16] Chang-Wei H, Chi-Te S, Yi-Ping C, Jyh-Horng C, Study of Human Affective Response on Multimedia Contents, World Congress of Medical Physics and Biomedical Engineering 2006, vol.2, Track 06, pp. 787-791, 2006.

[17] Asako H, Influence of emotion-including film stimuli on autonomic response specificity, Japanese Journal of Physiological Psychology and Psychophysiology, Vol.20, No.1, 2002 (in Japanese).

[18] Christian S, Martin E, Silke SN, Gig S, Andreas H, Emotion Detection: Application of the Valence Arousal Space for Rapid Biological Usability Testing to enhance Universal Access, HCII Conference San Diego, Springer Lecture Notes in Computer Science, 2009.

[19] Simons RF, Detenber BH, Roedema TM, Reiss JE, Emotion-processing in three systems: The medium and the message, University of Delaware, Psychophysiology, Vol.36, No.50, 619-627, 1999.

[20] Thayer JF, Ahs F, Fredrikson M, Sollers JJ 3rd, Wager TD, A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health, Neuroscience & Biobehavioral Reviews, Vol. 36, Issue 2, 747-756, 2012.