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A personal character model of affect, behavior and cognition for individual-like research ☆

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ABSTRACT

Humanoid robots, avatars, as well as some machines or tools possessing distinctive human features or characteristics, have been studied and developed in recent years. Alongside these developments, a new research area has emerged, known as individual-like research, the aim of which is the creation of physical or digital entities that resemble, to a certain extent, an existing human individual. Such individual-like entities could generate novel and as yet undreamed-of applications in fields such as lifestyle management. A general or comprehensive model of an individual's character is the key to individual-like research. Derived from the personality model in psychology, this paper proposes a structuralized and computable model, namely the Personal Character Model of affect, behavior and cognition (ABC). We first assign mathematical abstractions to the proposed personal character model, then present a general computing process of personal character in the model, and finally perform an experiment to collect the state data of twenty subjects and further analyze the results pertaining to personal emotional stability and attention ability, as well as the relational characteristic of each subject's affect and cognition.

1. Introduction

Humanoid robots, avatars, as well as some machines or tools possessing distinctive human features or characteristics, have been studied and developed in recent years, e.g., the "Cog" from MIT, the "Nao" developed by Aldebaran Robots, the "Atlas" from Boston Dynamics and the popular "Pepper" from Softbank Robotics. Alongside these developments, a research area has emerged, known as individual-like research, the aim of which is the creation of physical or digital entities that resemble, to a certain extent, an existing human individual. H. Ishiguro created the physical entity "Geminoid", an individual-like robot that "works as a duplicate of an existing person", and created a Geminoid [1]. In addition, "Virtual Teresa Teng", created by the company "Digital Domain", is a digital entity derived from individual-like research [2]. The main difference between humanoids and individual-like entities lies in the nature of their counterparts. Humanoid entities usually have no specific counterpart in a certain individual, while an individual-like object or entity could be regarded as a humanoid that resembles a specific existing person as a counterpart.

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The individual-like object could make possible the development of fantastic applications, such as the virtual clone of an individual. A fictional example is "Greta" in the "White Christmas" episode of the futuristic TV series "Black Mirror". Greta's copy knows exactly how Greta likes everything, and provides personal assistance, e.g., waking her up according to her sleep state, warming her office to her preferred temperature, and helping her organize her work and social schedules. Similar to this idea, the project "Augmented Eternity", created by the MIT Media Lab, aimed at creating a user's digital identity from digital footprints left by the user on the Internet. Such a personal digital identity could be rendered as a chatbot to chat with others instead of the user themselves. Another possible application is individual immortality. The concept of digital immortality has attracted many scientists' interest. In early 2001, Microsoft launched a project named "Cyber All Project", which aimed at creating a digital "you", where at least part of "you" would be able to communicate with the future through endless experience and learning [3]. The "Cyber-I" proposed by J. Ma in 2009, aimed at developinga comprehensive understanding of a person (a counterpart of an individual in digital space), e.g., possessing emotions, behaviors, and cognition, to simulate their decision-making indifferent situations [4]. Some work has been carried out to approach Cyber-I, such as the Cyber-I modeling platform and a growable mechanism [5]. The growable mechanism which consists of three methods, can promote the Cyber-I to grow 'closer' to its counterpart and 'bigger' and 'higher'.

In order to attain the possible applications mentioned above, one of the crucial issues in individual-like research is to build a comprehensive model of an individual. Analogous to the concept of the Turing test, a qualified individual-like object is required to pass the individual Turing test. As developed by Alan Turing in 1950, the Turing test is to evaluate a machine's ability to exhibit intelligent behavior indistinguishable from that of a human [6]. The individual Turing test is to evaluate how indistinguishable a machine's likeness is from the individual it resembles. For example, an individual's friend as evaluator chats remotely with an account, while responses would be made by this person and his individual-like machine alternately. If the evaluator is unable to distinguish the person and the individual-like machine, that indicates the machine can pass the individual Turing test.

Some projects have been founded to create an individual-like avatar publicly from its users' data, e.g., "ETER9" and "the CyBeRev project". Due to the lack of a general and computable model of the individual, current progress in individual-like research is far from passing the individual Turing test. Hence, a general or comprehensive description of the individual is necessary for individual-like research. According to psychology, personality refers to individual differences in characteristic patterns of thinking, feeling and behaving. Personality is the key to a distinctive description of the individual. To achieve a general and computable model of an individual, a model is proposed which consists of personal characteristics that make the model distinct from others. Such a model,possessing a collection of personal characteristics, is named as the Personal Character Model. Character refers to all the qualities and features that make a person different from others [7].

Derived from the work of a number of differential psychologists and personality psychologists, the Personal Character Model proposed in this research consists of two kinds of characteristics. One is the characteristics of affect (what one feels), behavior (how one acts) and cognition (what one thinks) [8]. Considering the relationships between these three aspects (e.g., behavior is the external expression of affect and cognition), the other characteristic is the relational characteristic. The relational characteristic consists of three pairs of relational characteristics between two of the three characteristics of affect, behavior and cognition. Furthermore, a general computing process of the personal character model is presented in this research to compute personal characteristics from an individual's timely state by a series of state features. To verify the feasibility of the model's computing process, an experiment collecting data of twenty subjects under different conditions was performed. Emotional stability and attention ability were chosen for the analysis of affect and cognition characteristics, respectively. The relationship between these two characteristics was computed and analysed as well.

The remainder of this paper is organized as follows. The next section summarizes related research efforts from different fields and clarifying the primary objective of our research. The proposed model is illustrated in Section 3. Section 4 describes a general computing process of the proposed model. Section 5 presents case studies of model computation, as well as the analysis and evaluation of modeling results. Conclusions and future work are outlined in the last section.

2. Research background and objective

Much work is related to this research. To clarify the main work and objective in our research, we summarized research in three aspects in this section, and describe the similarity to and specific objective of our research in certain research areas.

2.1. From user modeling to human modeling

A user model is a collection and categorization of personal data associated with a specific user [9]. User models are widely applied in many different applications (APPs) to improve the user experience of human-computer interaction (HCI). In earlier times, some basic individual attributes, e.g., gender, age, and some computer settings were collected as user models to help computers improve HCI dynamically. With the emergence of the personal computer (PC), hundreds of applications with myriad purposes were developed to tailor computers to individual users' needs, thus making it possible for user models to collect domain-specific knowledge about users (educational background, skill at games, etc.). The advent of applications on remote servers being accessed by users over the Internet has meant that increasingly remote user models exist independently rather than being embedded within applications, e.g., the generic user model proposed by Kobsa [10]. Since smartphone and cellular networks allow constant access to the Internet, there is a growing trend towards a user model that accretes user knowledge, e.g., ubiquitous user modeling and lifelong user modeling, through ongoing monitoring of the user's APP usage.

As the Internet increases in complexity, the concept of the "user" seems to be becoming more and more vague. Users are everywhere, since most people have access to the Internet nowadays, to a greater or lesser extent. Hence, the modeling of an everyman has developed gradually. One popular field in human modeling is personality computing. In psychology, personality is the essential individual characteristic that makes a person different from others. Personality computing, as an aspect of human modeling, aims at inferring an individual's personality from their observable behavior and physiological and textual evidence [11]. The target of most personality computing is the computation of a comprehensive description of a subject's personality according to the "Big Five Personality Traits" (a description of personality with a five-factor structure). One example is a person computed to have a high degree of conscientiousness (one of the big five traits) being regarded as "always prepared" rather than "messy" [12]. However, due to the wide gap between the low-level information accessible to computers and high-level personality information, the current results of personality computing have not attained a high degree of accuracy [13]. Hence, one objective in this research is a structuralized model that would fill this gap and attain comprehensive personality computing. Derived from a personality model from psychology, the proposed personal character model consisting of personal characteristics derived from affect, behavior and cognition roles is intended to be the bridge between personality and the information accessible to computers.

2.2. From humanoid to individual-like research

In recent years, increasing numbers of humanoids are gradually playing a greater role in people's lives. The term "humanoid" derives from the word human and '-oid' (resembling), defined by the Oxford English Dictionary as "a machine or creature that looks and behaves like a human". The first humanoid may date back to the "Automaton Knight" made by Leonardo da Vinci around the year 1495 [14]. Currently, in the mainstream, the term "humanoids" refers to a kind of robot or digital avatar with distinctly human characteristics, such as a human-like face, ability to walk on two legs, or even the ability to think in a human way [15]. Thanks to these human characteristics, humanoids could provide a wider range of services to people than other robots. They are potentially able to assume human tasks (e.g., dangerous rescues and distant space exploration), and able to communicate and cooperate with people in a natural way (e.g., online education through a digital avatar) and for entertainment (e.g., in roles as virtual characters in computer games). Within humanoid research, efforts into creating an object that can assimilate the characteristics of a certain individual, in terms of their appearance, behavior or even thought, are classified into a field distinct from humanoids, named individual-like research. The classification and representative projects of individual-like research is shown in Fig. 1.

Individual-like (IL) research can be classified into three aspects: robot, avatar, and mind. The most common one is the robot. For example, the robot "Geminoid HI-2" created by H. Ishiguro in 2007, resembled its creator in appearance and voice. The well-known robot Sophia, activated in 2016, which was the first robot granted Saudi Arabian citizenship, was modeled from its prototype - the famous actress Audrey Hepburn. Instead of creating a robot that resembles a certain individual, there exist some individual-like virtual avatars. For example, the "Virtual Teresa Teng", created by the company "Digital Domain" in 2013, which had a surprise original performance, resembles its prototype Teresa Teng [2].

In addition to these examples of research into physical or virtual appearance, some research efforts aim at modeling an individual's mind, for it is the crux to understanding an individual fully. Dating back to 1994, R. Clarke proposed the concept of a "digital persona", as "a model of an individual's public personality based on data and maintained by transactions" [16]. In 2012, M. Rothblatt proposed "The Terasem Mind Uploading Experiment", which aimed at uploading an individual's consciousness into the cloud [17]. She created two projects to realize this idea, the "CyBeRev" project and "Lifenaut" [18]. Particularly, the "Cyber-Anima" proposed by Y. Li, aimed at the nature of a person's mind [19]. According to the research efforts mentioned above, continuously provided personal data is the foundation to the model of an individual's mind. Hence, in this research, the computing of the proposed model is also based on the individual's continuous data from differential sources, such data being named as personal big data. Besides, few of these research efforts have a general model for the modeling of an individual's mind. Therefore, one objective in this research is a structuralized and computable model of the individual's mind from personal big data.

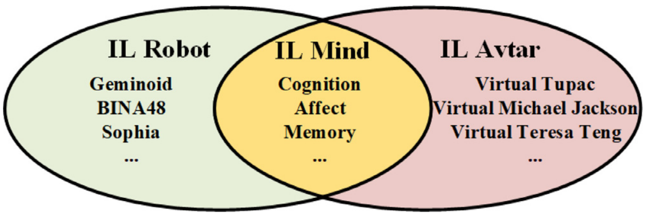

Fig. 1. Classification and representative projects of individual-like research.

2.3. From general psychological models to individual/personal character modeling

Although there has been much work on individual-like research, less progress has been made in modeling an individual's mind. One hindrance to progress is the lack of a full understanding of the mechanism of the human mind. Some research, e.g., the Geminoid, has made a startling impression. A real individual could control the Geminoid via telecommunications. It is the best compromise for the development of an individual-like robot, since no individual mind model has been created to this point. However, to achieve digital immortality and an even greater individual synthesis, the understanding of an individual is necessary. Hence, the objective in this research aims at creating an integrated model to describe the individual. The basic requirement of this model is the identification of an individual from among a group of people by using such an individual model. In this research, the object model of individual description is based on research in personality psychology, because of its achievement in describing the variation among individuals, as shown in Fig. 2.

According to G. Allport, personality is the key to understanding the variation in how people feel, act, think and want. Currently, some psychologists think that personality consists of four aspects, namely affect, behavior, cognition, and desire. Specifically, W. Revelle proposed a model of personality, as shown on the left side of Fig. 2, while other psychologists argue about desire as a personality trait. In addition, to the best of our knowledge, there has been little progress on desire (motivation) computing. Derived from the model of personality above and considering the low computability of desire, the object model of an individual is regarded as consisting of affect, behavior, and cognition to describe the individual's characteristics.

Affect, behavior, and cognition are not separated but interact with each other. Affect in psychology refers to the description of the experience of feeling or emotion. Behavior is the range of action made by individuals, while cognition, according to its definition in the Oxford English Dictionary, is "the mental action or process of acquiring knowledge and understanding through thought, experience and the senses". Some psychologists insist that affect could profoundly influence key elements of cognition (e.g., perception, attention and memory). To clarify the relationship between affect, behavior, and cognition, a general process of these three elements is shown in Fig. 3. Fig. 3 summarizes the process of affect, behavior, and cognition from MAX's overall cognitive architecture [20] and the control that affect exerts over cognitive functions. For an individual in a specific environment, chatting with friends for example, the cognition function perceives information from the environment continually, e.g., watching friends' facial expressions and listening to their voices. The cognition function processes the information perceived from the environment and generates the behavior command as a cognitive expression (e.g., a response in agreement to a friend's opinion) as well as a specific emotion (e.g., joy). The affect function regulated by cognition would further influence the cognition process (e.g., turn-taking and interruption during conversation), and generate a particular behavior as an expression of affect (e.g., laughing). The behavior function determines the final action by combining behavior commands from affect and cognition. Although the actual process is much more complicated than this general process description of affect, behavior, and cognition, it is undeniable that these three functions are integrated as a whole with compact interaction, representing the individual's mind in interaction with outer environments. Hence, the proposed model in this research is based on characteristics in terms ofaffect, behavior and cognition, and their relations. Because of

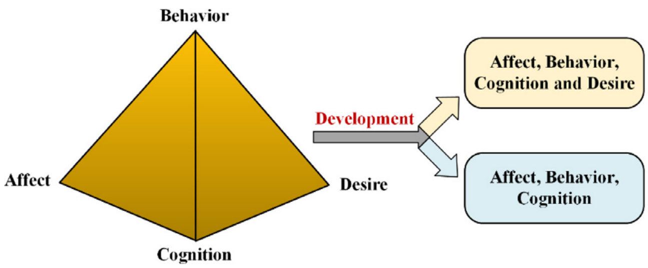

Fig. 2. The ABCD model of personality of William Revelle and its developments.

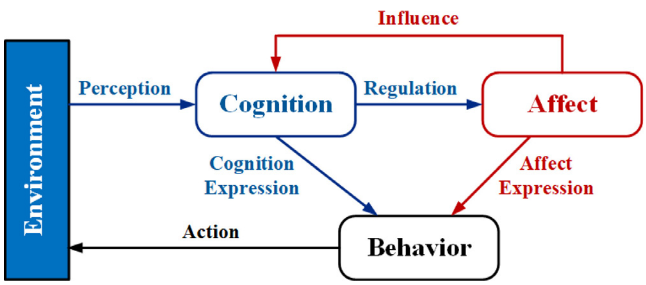

Fig. 3. Process and relations of affect, behavior and cognition.

the lack of computability from personal data in the psychological model, one objective in this research is a computable model that could generate personal characteristics automatically from greater amounts of personal big data. Accordingly, this study proposes a general computing process of personal characteristics from a person's temporal state to the features of such a state, and from these features of states to personal characteristics.

In summary, the objective in this research is a structuralized and computable model of an individual's characteristics to bridge the gap between personality and personal data by computing the model from personal big data. The detailed description of the Personal Character Model is presented in the next section, and a personal character computing process and associated case studies are given respectively in the remaining two sections.

3. Personal character model of affect, behavior and cognition

This section presents the proposed Personal Character Model in detail (PCM). Specifically, the abstraction and representation of the PCM is described first. Then criteria for the PCM are described and discussed. Two kinds of model elements and examples of each are discussed subsequently.

3.1. Abstraction and representation of personal character model

A person's characteristics are his/her stable features across time and space. Since a variety of characteristics exist within a person, the personal character model is therefore proposed to describe personal characteristics in multiple aspects. A person's character is the integration of the person's characteristics that make him/her distinct from other people. Derived from personality psychology, the personal character involves affect characteristics, behavior characteristics, and cognition characteristics. Fig. 4 illustrates the basic aspects and structure of the personal character model.

Differential psychology seeks to understand variation in how people feel, act, think and want. Accordingly, stable individual differences are classified into four domains: affect, behavior, cognition, and motivation (desire) [21]. Similarly, personality psychology defines the personality as the character set of behavior, cognition and emotional patterns that evolve from biological and environmental factors [8], while D. G. Winter et al., doubted that motivation was one such characteristic [22]. Hence, affect, behavior, and cognition are selected as the three aspects of characteristics and are denoted by A, B, and C. Personal characteristics, being fundamental elements of the PCM, are denoted by X, whichrefers to the term "characteristic" ("$\chi\alpha\rho\alpha\kappa\tau\eta\rho\iota\sigma\tau\iota\kappa\acute{o}\varsigma$" in ancient Greek).

Fig. 4 describes the PCM in a way of graphical representation using a triangular structure, with three nodes and three edges. Therefore, personal characteristics in the PCM are mathematically formulated as given below,

$$PCM = (X_{Nd}, X_{Ed}) \tag{1}$$

where X_{Nd} represents all nodes in the PCM, and X_{Ed} denotes all edges in the PCM. Each node refers to characteristics in respect to affect, behavior or cognition. Then the X_{Nd} is formulated as below,

$$X_{Nd} = \{X_A, X_B, X_C\} \tag{2}$$

where X_A, X_B and X_C indicate the characteristics in the three aspects of affect, behavior and cognition, respectively.

The edges of the PCM refer to three pairs of relational characteristics between any two of X_A, X_B and X_C. Take X_A and X_B as an example. The relational characteristic could be a habitually clenched fist when feeling stress during a presentation. The characteristics "feeling stressed when making a presentation" and "clenching fist when making a presentation" belong to the person's X_A and X_B. The characteristic "clenching fist to decompress when feeling stressed" refers to one of the relational characteristics between X_A and X_B in this scenario. Hence, X_{Ed} is formulated as given below,

$$X_{Ed} = \{R_{AB}, R_{BC}, R_{AC}\} \tag{3}$$

where, R_{AB},R_{BC} and R_{AC} represent the relational characteristics between any two aspects of affect, behavior and cognition.

In general, the PCM consists of two parts: three characteristics of affect, behavior and cognition, and their relationships, which are discussed in the Sections 3 and 4, respectively.

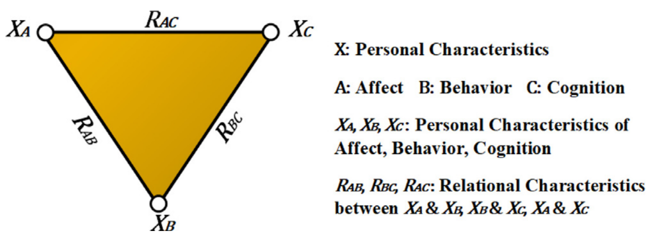

Fig. 4. Basic aspects and structure of personal character model.

3.2. Criteria of personal characteristics

The characteristics of a person have been defined in many different research fields. The New Oxford Dictionary defines a characteristic as "a feature or quality belonging typically to a person and serving to identify them". The psychologist R. A. Roe summarized individual characteristics as the attributes of a person, e.g., body length and sex in the common sense, and "theoretical constructs serving to explain and predict behavior" [23]. Regarding the PCM, personal characteristics should be characteristics related to affect, behavior, and cognition. However, this description is far from meeting the model's requirements. Accordingly, two criteria for personal characteristics are given for the guidance of further PCM computing.

For the sake of clarifying the two criteria of personal characteristics, all human beings are formulated as given below,

$$H = \{H_1, H_2, \ldots, H_n\} \quad (4)$$

where H denotes all human beings, and n is the total number of human beings. Suppose H_k refers to the kth individual among human beings, and all his/her personal characteristics are represented by $X_k = \{X_1^k, X_2^k, \ldots, X_{J^k}^k\}$, where J^k is the total number of personal characteristics for the individual H_k.

3.2.1. Individual difference of personal characteristics

To reflect the individual difference, each personal characteristic should satisfy the following criterion:

$$\forall X_j^k : \left(X_j^k \in X_k\right) \wedge \left(X_j^k \notin X_p\right),\ j \in \left\{1,\ 2,\ \ldots, J^k\right\},\ k, p \in \{1,\ 2,\ \ldots, n\},\ k \neq p \quad (5)$$

where, for any element X_j^k in X_k belonging to a person H_k, there exists at least one other person H_p without the characteristic X_j^k. According to this criterion, the special behavior habit, e.g., "clenching fist when make a presentation", and a stable emotion stimulus, e.g., "feeling stressed when making a presentation", are regarded as two personal characteristics whereas general features of each normal person, e.g., "the ability to behave, to think or to feel", are not personal characteristics. In brief, this criterion is one of the basic requirements of each personal characteristic in the PCM.

3.2.2. Individuality of personal characteristics

Individuality is derived from differential psychology and personality psychology, referring to the uniqueness of a person compared to the whole human population. A person's entire range of personal characteristics shows their individuality as well. Suppose the collection of a person's entire personal characteristics were formulated as below,

$$\mathfrak{X}(H_k) = X^k,\ H_k \in\ H \quad (6)$$

where the function $\mathfrak{X}(H_k)$ represents the process of collecting all the personal characteristics (i.e., personal characteristics in terms of affect, behaviour, cognition and their correlational characteristics) of the person H_k. The collection of H_k's personal characteristics is denoted as X^k. The whole collection of characteristics X^k of person H_k should satisfy the following criterion,

$$card\left(\mathfrak{X}^{-1}\left(X^k\right)\right) \ll n \quad (7)$$

where the function $\mathfrak{X}^{-1}(X^k)$ indicates the process of identifying people who all hold the personal characteristics X^k. This criterion indicates the number of people who hold the collection of personal characteristics X^k is much lower than the whole population n, whilst not guaranteed to be completely unique. In other words, the unique personal characteristics of an individual cannot guarantee the identification of him or her from others. It is possible that two people have almost the same identical personal characteristics (identical twins, for instance), although the chances are slim.

3.3. Personal characteristics of affect, behavior and cognition

This section focuses on mathematical abstractions of the personal characteristics of *A*, *B*, and *C*.

3.3.1. Affect characteristics

Affect characteristics are the stable characteristics of affectthat belonging typically to a person and serve to identify them. Affect characteristics X_A is formulated as below,

$$X_A = \{X_{A_1}, X_{A_2}, \ldots, X_{A_a}\} \quad (8)$$

where X_{A_1} is the first element of X_A. The total number of elements of affect characteristics X_A is a. Each element of X_A refers to an aspect of affect characteristics.

One psychologist has proposed a variety of characteristics in terms of affect. Each characteristic belongs to an affect characteristic. Take the "affect temperament" as an example. The affect temperament refers to " an average of a person's emotional state across a representative variety of life situations" [24]. Assume the affect temperament is denoted by $X_{A_{Tmp}}$. According to A. Mehrabian, the affect temperament consists of three factors, namely, pleasure (Positive/Negative), arousability (Low/High) and dominance (Low/High). Pleasure represents a person's affect state across situations and time, while arousability indicates the strength of emotion during changing situations. Dominance evaluates the person's ability to control their emotion over their living circumstances. These stable factors of a person make them different from others. Hence, $X_{A_{Tmp}}$ is expressed as follows,

$$X_{A_{Tmp}} = \{Pleasure,\ Arousability, Dominance\} \tag{9}$$

where, pleasure, arousability, and dominance consist of the affect temperament $X_{A_{Tmp}}$.

3.3.2. Behavior characteristics

Diversity of behavior exists. Behavior characteristics X_B is formulated as below.

$$X_B = \left\{X_{B_1}, X_{B_2}, \ldots, X_{B_b}\right\} \tag{10}$$

where X_{B_1} is the first element of X_B. The total element number of behavior characteristics X_B is b. Each element of X_B refers to an aspect of behavior characteristics.

Generally, behavior could be classified into three classes from the body's inner workings to external manifestations. Inner behavior is physiological behavior (e.g., mind waves), which happens corporally, while motive behavior (e.g., gestures, facial expressions) happens based on the body. Language is expressed externally. Characteristics of these three classes of behavior are regarded as three aspects of behavior characteristics. The behavior characteristics of physiology, motion, and language are denoted by $X_{B_{Phy}}$, $X_{B_{Mot}}$, $X_{B_{Lan}}$, respectively. $X_{B_{Phy}}$,$X_{B_{Mot}}$,$X_{B_{Lan}}$ belong to the behavior characteristics X_B.

A person's speaking voice is an aspect of their physiological behavior. According to acoustic research, acoustic features (pitch, mean energy, etc.) across time belong to an individual's behavior characteristics in a physiological sense. Similarly, particular gestures (e.g., showing a single-handed gesture "Okay" to express agreement), and specific facial expressions belong to motion characteristics. Accordingly, language features during changing situations, such as the mean number of words per sentence, preferred words, and negations (e.g., no, not, and can't) belong to an individual's language characteristics.

3.3.3. Cognition characteristics

Cognition characteristics X_C is formulated as below,

$$X_C = \{X_{C_1}, X_{C_2}, \ldots, X_{C_c}\} \tag{11}$$

where, X_{C_1} is the first element of X_C. The total element number of cognition characteristics X_C is c. Each element of X_C refers to an aspect of X_C.

According to cognitive psychology, cognition is classified into four fundamental functions (perception, attention, memory, and learning) and a set of high-level functions (e.g., production of language, knowledge, judgment, reasoning). Each function has its own characteristics. The characteristics of the four fundamental cognition functions could be denoted by $X_{C_{Per}}$, $X_{C_{Att}}$, $X_{C_{Mem}}$ and $X_{C_{Lea}}$. Hence, these characteristics belong to the cognition characteristics, and are formulated as below,

$$\{X_{C_{Per}},\ X_{C_{Att}},\ X_{C_{Mem}}, X_{C_{Lea}}\} \subseteq X_C \tag{12}$$

As to the perception characteristics $X_{C_{Per}}$, five elements are based on the fivesenses, and the $X_{C_{Per}}$ is formulated as below,

$$X_{C_{Per}} = \left\{X_{C_{Sight}}, X_{C_{Hearing}}, X_{C_{Taste}}, X_{C_{Smell}}, X_{C_{Touch}}\right\} \tag{13}$$

where, $X_{C_{Sight}}$, $X_{C_{Hearing}}$, $X_{C_{Taste}}$, $X_{C_{Smell}}$, $X_{C_{Touch}}$ refer to characteristics of sight, hearing, taste, smell and touch, respectively. In addition, one of the attention characteristics $X_{C_{Att}}$ is the sensitivity to the gaze of others.

3.4. Relational characteristics among affect, behavior and cognition

As discussed in the last section, some characteristics could be categorized as affect, behavior, and cognition. These characteristics are not always independent from one another. In other words, they might correlate with other personal characteristics. Previous research into personality psychology suggests that a person with high emotional intensity (registering a stronger emotional experience than those with low emotional intensity in the face of the same stimulus), would display rich gesture usage. There exists a correlation between emotional intensity (as one of the characteristics of affect) and a predisposition to use gesture (as one of the characteristics of behavior). Furthermore, it has been found that people from different cultures (Asian vs. European) show different patterns of correlation between emotional intensity and gesture preference [25]. Therefore, such individual difference or relational characteristics exists between two personal characteristics. To be more specific, a relational characteristic is defined as the individual difference in correlation between two personal characteristics. In this study, personal characteristics are subdivided into three categories, including affect, behavior, and cognition. Therefore, the three categories of relational characteristics are the relational characteristics of affect and behavior, of affect and cognition, and of behavior and cognition, which are denoted as R_{AB}, R_{AC}, and R_{BC}, respectively. Take R_{AB} as an example. R_{AB} is regarded as the universal relational characteristics between X_A and X_B, and formulated as below,

$$R_{AB} = \begin{bmatrix} R_{(A_1,B_1)} & R_{(A_1,B_2)} & \cdots & R_{(A_1,B_b)} \\ R_{(A_2,B_1)} & R_{(A_2,B_2)} & \cdots & R_{(A_2,B_b)} \\ \vdots & \vdots & \vdots & \vdots \\ R_{(A_a,B_1)} & R_{(A_a,B_2)} & \cdots & R_{(A_a,B_b)} \end{bmatrix} \tag{14}$$

where $R_{(A_i,B_j)}$ $(i \in \{1, 2, ..., a\}, j \in \{1, 2, ..., b\})$ refers to the set of personal characteristics which shows relational characteristics between X_{A_i} and X_{B_j}. Specifically, if $R_{(A_i,B_j)}$ is an empty set, it indicates that there are no obvious relational characteristics between X_{A_i} and X_{B_j}.

Relational characteristics among each two of affect, behaviour, and cognition are described above. To better illustrate relational characteristics, some examples of each are given below.

3.4.1. Examples of relational characteristics between affect and behavior

Posture is a typical behavior to express emotion. Some research has shown that people from different cultures use their bodies differently to express the same emotion. For example, an Indian would use gesture more to express emotion, such as shaking a hand to express excitement or disappointment, but an American uses head movement and exaggerated facial expressions more to display these two emotions. Proxemics is another example of a relational characteristic between affect and behavior. Proxemics is the study of the specific distance at which a person feels most comfortable in face-to-face interaction with another person. The distance varies with people and is different for each person experiencing a specific emotion. The person's stable proxemic distance under a certain affectis regarded as one of the relational characteristics between affect and behavior.

3.4.2. Examples of relational characteristics between affect and cognition

One of relational characteristics between affect and cognition is emotional disposition. According to psychology, "emotional disposition is a persistent tendency to feel a certain kind of emotion in the presence of a certain object". Hence, an individual's stable emotional disposition when memorizing something or paying attention to something are their relational characteristics between affect and cognition. For instance, people have different reactions to a goal being scored in a soccer game and the reaction is based onsupport of team. The influence of a certain emotion on cognition is another example of a relational characteristic between affect and cognition. According to the research of J. Leu, J. Wang, et al., in positive situations, Asian-Americans tend to be more pessimistic than European Americans [26].

3.4.3. Examples of relational characteristics between behavior and cognition

The context of speech or writing is not only a kind of behavior, but also a reflection of a person's cognition. Hence, a person's language style is one of his relational characteristics between behavior and cognition. Usually, language style is characterized into six categories: character, lexis, syntax, semantics, structure and domain-specificity. Take syntax as an example. A person might frequently express their opinion using a stock vocabulary of words and phrases and complex syntax under a normal cognition state, but would utter different words and phrases and use simpler or even incorrect syntax when they are in an abnormal cognition state.

4. The general process of personal character computing

In this section, the general process of personal character computing is clarified, as shown in Fig. 5. The fundamental idea behind personal character computing is to recognize the personal state from a special dataset about the individual named personal big data (PBD). Then, a multitude of features of that personal state is identified. Such features would be used in the personal characteristic computation based on the incorporation of several classification or regression algorithms. The relational characteristic would be analyzed from each of two types of personal characteristics (i.e., personal characteristics of affect, behavior, and cognition). Each step of the computing process will be elaborated in the following paragraph.

As shown on the left of Fig. 5, Personal big data (PBD) is a large and continuous collection of rich data that is related to or generated by a specific person. PBD is collected from various data sources, e.g., smartphones, wearables, social Apps, or even questionnaires. Three features of PBD make it possible for the comprehensive computation of the PCM, namely large quantity, multi-dimensionality, and continuous provision. Specifically, the provision of a large amount of data from different

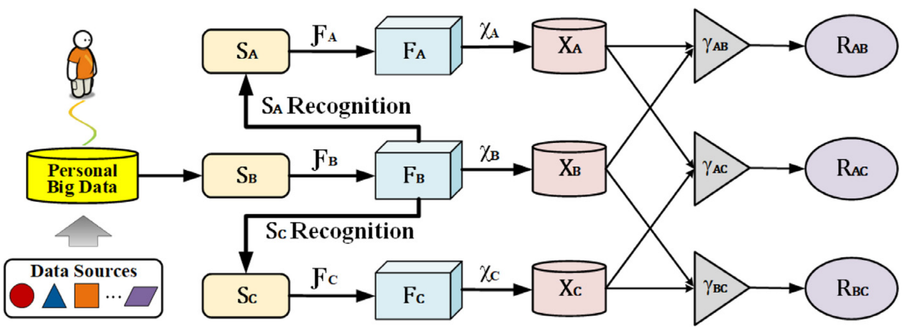

Fig. 5. The general process of personal character computing.

sources represents the large quantity. Multi-dimensionality infers the data would cover a variety of aspects of an individual, while continuous provision indicates the personal data would be provided continuously. PBD would be collected irrespective of consideration of the experimental environment or the scenario. For the data collected without considering the scenario, some lifelogging techniques, such as the context-awareness which was implemented in our previous work [27], should be used for daily data collection. For specially designed experiments, such as watching a movie to arouse a certain emotion, heterogenous data from smartphone and wearables should be collected at the same time. Its value should be processed by 0–1 normalization or z-score normalization.

In machine learning, a feature is an individual measurable property that represents some objects or phenomena. A set of numeric features is selected as a feature vector for the training of machine learning, such as the movement of the mouth and eye as two features of the human face, while the trained model of the mouth and eye are two different characteristics of humans. Following this process, the process of personal character computing consists of three steps, as shown in the center and on the right of Fig. 5. Specifically, the personal data would be processed into personal states, personal features, and personal characteristics sequentially. The personal stateis defined as the particular condition of an individual at a specific time, and it is denotes by S. Specifically, the state S is formulated as follows,

$$S = \{S_A, S_B, S_C\} \tag{15}$$

where S_A, S_B, S_C refers to the state of affect, behavior and cognition, respectively. For example, Ekman's six basic emotions (Happiness, Sadness, Anger, Fear, Disgust, Surprise) experienced within a short time and A. Mehrabian's PAD (pleasure, arousal and dominance) emotional state model belong to emotion states S_A, while heartbeat and body movement, gesture, facial and body expression belong to behavior states S_B. Focus, relaxation, and interest belong to cognition states S_C.

S_A, S_B, S_C would represent their own features. This feature is defined as the feature of personal states (Such as timely emotion arousal value) or the data feature that indicates personal conditions (the frequency of blood volume pulse (BVP) indicating heart rate), and it is denoted by F. Hence, the feature F is formulated as follows,

$$F = \{F_A, F_B, F_C\} \tag{16}$$

where F_A, F_B, F_C refer to the feature of affect, behavior and cognition, respectively, andthe process of featuring the state is formulated as below,

$$\mathcal{F}(S) = F \tag{17}$$

where $\mathcal{F}(S)$ refers to the function of deriving the feature F from the state S.

Feature F basically contains two types: (1) the features of personal condition and (2) the data features that indicate personal condition or benefit its recognition. As for the first type, some common statistic features could be measured, such as mean, maximum, minimum, standard deviation (STD), skewness, and% of the feature value above and/or below Mean ± STD. As for the second type, a series of data features would be selected on the basis of whether such data features are important for the recognition of personal condition. For example, heart rate is an important data feature because it could benefit the recognition of strong emotional state, such as happiness and anxiety.

The second step is the characterization of the feature of A, B, and C to its personal characteristics respectively. This process is formulated as below,

$$\chi(F) = X \tag{18}$$

where $\chi(F)$ refers to the function of characterizing the features F to the personal characteristics X. The computing algorithm is formulated on the basis of classification or regression, which map the selected feature F_i to a certain personal characteristic X_i. Specifically, the algorithm could be classified into supervised algorithms (e.g., Linear Regression, Support Vector Machine (SVM), Decision Tree (DT), Naïve Bayes (NB)) and unsupervised algorithms (e.g. DBSCAN classification, K-Means Classification), due to the result of personal characteristic as the annotation.

The last step of the PCM computing process is the computing of relational characteristics and it is formulated as below,

$$\gamma_{\alpha\beta} = \gamma\left(X_\alpha, X_\beta\right) = R_{\alpha\beta},\ \ \alpha, \beta \in \{A,\ B, C\} \wedge \alpha \neq \beta \tag{19}$$

where, $\gamma_{\alpha\beta}$ represent the process of relational characteristics calculation between X_α and X_β(α,β represent one of A, B, C). The result is denoted by $R_{\alpha\beta}$. The basic process of relational characteristic calculation is conducted by analyzing the correlation between each of two personal characteristics, including affect, behavior, and cognition under a certain personal characteristic. If a stable individual difference exists among people with different personal characteristics, then that is one of the relational characteristics.

Two examples are given to clarify the process of PCM computing. In terms of the affect, suppose S_A is one of the six basic emotions experienced in a certain time, and $\mathcal{F}_A$ is the process of measuring the mean intensity and variation (as F_A) of emotions from S_A over a period of time. $\chi_A$is the process of measuring the emotional stability (one of X_A) from F_A in different scenarios.Similarly, suppose S_C is the focus condition in a certain time, and $\mathcal{F}_C$ is the process of measuring the focus intensity and variation (as F_C) of the focus condition from S_C over a period of time. χ_C is the process of measuring the attention ability (one of X_C) from F_C in different scenarios.

According to the affect characteristic and cognition characteristic of the individual measured above, relational characteristics R_{AC} between emotional stability and attention ability can be measured by the function γ_{AC}. This relation indicates a single difference in an individual in their affect and cognition.

5. Studies on personal emotional stability and attention ability

The personal character model is employed to describe the individual difference in terms of affect, behavior, cognition, as well as their relations. To better understand the model elements, we calculate the personal characteristics and relational characteristics using the proposed personal character computing method. Due to the personal characteristics of behavior (left-handedness or right-handedness, for instance) being easier to perceive than personal characteristics of affect and cognition, emotional stability and attention ability are selected as affect and cognition, respectively, to better describe the individual difference in affect and cognition.

The organization of this section is listed as follows. The first section is the experiment description. The second section shows the particular personal characteristics and relational characteristics that need to be computed from the collected data. The third and fourth sections are two case studies based on the data from the experiment showing the process, result, and evaluation of affect and cognition characteristics, respectively. The last section shows the result of relational characteristics computing between affect and cognition.

5.1. Experiment description

The participants in this study were ten women and ten men between the ages of 23–29 years ($M \pm SD = 25.89 \pm 2.26$) recruited from Hosei university, made up of five undergraduates, ten postgraduates and five doctoral students. All the participants were Chinese, and all of the participants were single. The experiment process is shown in Fig. 6.

As shown on the left of Fig. 6, all the participants were required to wear two wearable devices and an earplug during the whole experiment. The first wearable is "Emotiv Insight", a headset which collects electro-encephalographic (EEG) data. The second was "Spire Stone", a small sensor attached to the belt which measures breathing rate. The earplug was the "BOSE QC30", which has an embedded noise reduction module to provide highly immersive music playback.

Each participant underwent three rounds of experiments, as shown in the center right of Fig. 6. For each round, they were required to be calmed down through guidance from "Spire Stone APP" (following guidance to slow their breathing rate to under ten times per minute), as the first step. Secondly, a short news clip and a questionnaire were given to them. They were requested to find the right answer on the questionnaire from the information provided by a news story as quickly as possible. The questionnaire consisted of ten questions that asked the participant to fill in missing information according to the short news clip. For example, one question is "In 1960, ___% of children in the US had a health condition severe enough to interfere with their usual daily activities". While reading and answering the questions, the participant needed to listen to a certain type of music. For the first round, the participant listened in silence. For the second and the third rounds, the participant listened to their favorite music and specific music that they had never heard before, respectively. During the experiment, the timely excitement (arousal) value and attention (focus) values were recorded for further case studies. These two kinds of data were calculated by the "Emotiv Insight" device from its timely recorded EEG data representing the participant's level of emotional arousal and their level of concentration on one task without being distracted, respectively. The provision frequency of these two data was twice per second for both.

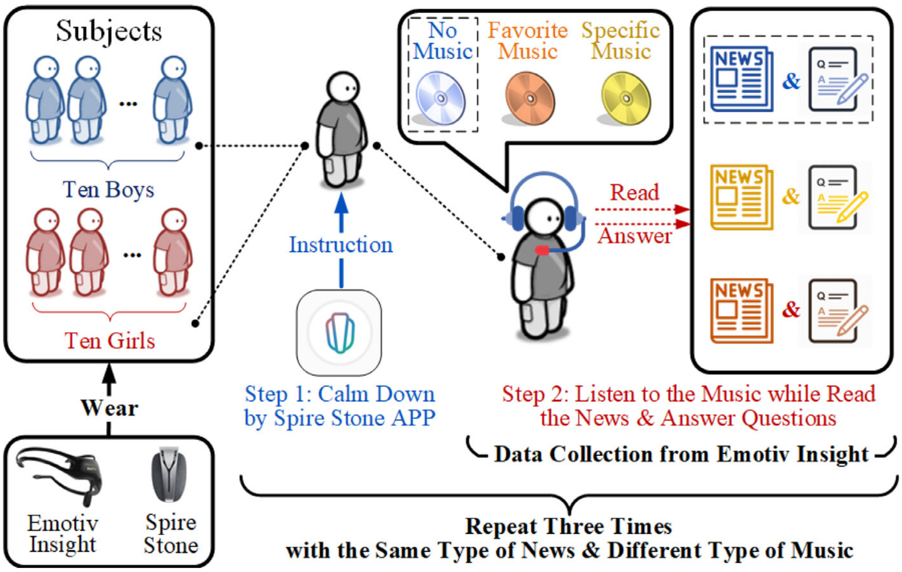

Fig. 6. Experiment process.

5.2. Emotional stability, attention ability and their relation

The personal characteristics of affect and cognition as well as relational characteristics between affect and cognition are selected to be measured separately from the twenty subjects' data collected by the experiment above, as shown in Fig. 7, in order to evaluate the feasibility of the computing process of the personal character model. Therefore, two characteristics are selected as the characteristics of affect and cognition, namely, emotional stability and attention ability. There are two reasons explaining why two personal characteristics of affect and cognition are selected and why the personal characteristic of behavior is disregarded. Firstly, the basic computing process of each personal characteristic is similar, no matter which characteristic it processes. The case is the same with relational characteristic computing. Secondly, psychologists have designed many psychological questionnaires to measure people's characteristics in affect and cognition. Yet the measurement of behavior is seldom conducted. We selected the personal characteristics of affect and cognition, because these results could be crosschecked with those calculated through psychological questionnaires. Moreover, the case studies of personal characteristics computing in affect and cognition could be applied to the computing of personal characteristics of behavior.

Emotional stability, also named "Neuroticism" in personality psychology, refers to a person's ability to maintain emotional balance under stressful circumstances [28]. A person with low emotional stability is less likely to evoke a strong emotional response to a general situation, and their emotional response is slower than that of people with high emotional stability. Hence, emotional stability is one of the key characteristics that reveal individual differences in affect.

Attention ability as one of the cognitioncharacteristics, refers to the ability to focus attention on a stimulus [29]. People that suffer from the well-known disorders Attention Deficit Hyperactive Disorder (ADHD) have poor attention ability. Hence, the ability to payattention is one of key characteristics in cognition that differentiates an individual. Therefore, this study selects two such individual natural attributes as the characteristics of affect and cognition. Analogous to the concentration game "spot the differences" as the stimuli to test attention ability in psychology, the task of finding an answer from a news extract is a stable and continuous stimulus for the participants in this experiment. Listening to different types of music functions as random interference, in line with previous research into music and emotion [30].

Computation of these two characteristics is shown in Fig. 7. The excitement series and focus series from the device "Emotiv Insight" calculated by EEG data (two data per second) are selected as the timely affect and cognition state. Each excitement and focus value represents the subject's emotional energy and the degree of concentration on an item at a certain time. A series of features are selected for the computation of characteristics. The feature combines two types: the feature value, and the feature series. The data series which is calculated to a single value belongs to the feature value, while the data series calculated to a series of features is named the feature series. An example would be the mean of an excitement series being the feature value, while the mean of the excitement series calculated every 10 s would be assigned to the feature series. The feature extraction from affect and cognition state is shown on the left of Fig. 7. Considering that the average experiment lasts about 10 min, t calculation every 10 s wouldn't generate an over-large dataset, yet it can provide enough data for personal characteristic computing. Irrespectively, the minimum measurable variation of emotion (from Emotiv Insight) is 10 s. Both affect and cognition features contain four common features of the data series, namely the maximum value, mean value, deviation value and amplitude value. In addition, the maximum duration from excitement to calmness ("DurationCam") and the frequency of excitement ("FreqExcite") are selected as two possible features for the computation of emotional stability, in accordance with several works on their measurement. The mean duration and stability of high focus ("DurationFocus" and "StabilityFocus") are selected as two possible features for the computation of attention ability. Feature values of the excitement series (F_{AV}) and feature values of the focus series (F_{CV}) are the controlling elements computing emotional stability and attention ability, respectively, according to the polynomial of each of their features. χ_A and χ_C are functions of emotional stability computing and attention ability computing, respectively. Specifically, emotional stability is calculated as the sum of each excitement feature with its corresponding coefficient α, while attention ability is

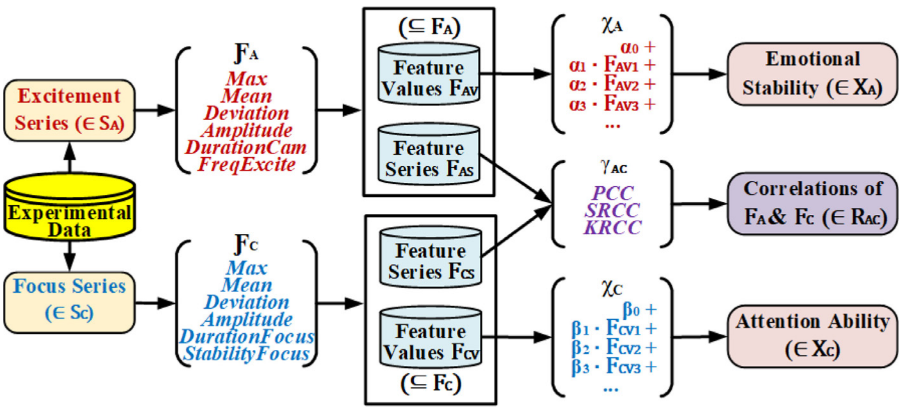

Fig. 7. Computing of emotional stability, attention ability and their relation.

calculated as the sum of each focus feature with its corresponding coefficient β. Each element of the affect feature series (F_{AS}) and cognition feature series (F_{CS}) are selected for further correlation analysis (γ_{AC}). There are basically two methods for feature process, namely feature selection (e.g., correlation-based feature selection (CFS)) and feature fusion (e.g., principal component analysis (PCA). CFS is used in this study, because it is easy to measure and compatible with multi-modal data. Accordingly, three common correlation coefficients are measured, the Pearson Correlation Coefficient (PCC), the Spearman Rank Correlation Coefficient (SRCC) and the Kendall Rank Correlation Coefficient (KRCC). These three correlation coefficients reflect the variation in degree of two random variables, and they are suitable for different types of variables. PCC is suitable for two changeable variables. For example, running speed and heartbeat value are correlated with one another. However, running fast or slow might not affect the heartbeat value. Therefore, PCC is not suitable for measuring the correlation between these two variables. Therefore, we select the three correlation coefficients to measure any potential correlations among the variables.

To evaluate emotional stability and attention ability computed according to the process of Fig. 7, each subject completed two psychology questionnaires (the Eysenck Personality Questionnaire and the Jasper/Goldberg Adult ADD Questionnaire) as reference for the evaluation of the computed characteristics. Their degree of similarity is selected as the evaluation criterion. The results and evaluations of personal characteristics mentioned above are illustrated in the next three sections.

5.3. Personal emotional stability computing and analysis

Following the computing of emotional stability illustrated in Fig. 7, six features are extracted from each subject's timely excitement series data. As shown in Fig. 8, six point sets represent twenty subjects' values for six features. The horizontal axis shows each of twenty subjects, while the vertical axis indicates the value of each of six features. Because the range of timely excitement value is [0, 1], features of maximum, mean, deviation and frequency of excitement are normalized into 0 to 1. To fit the point sets, the duration from excitement to calmness has been normalized by shortening it by a factor of 30.

The emotional stability of each subject is computed from the features extracted above, according to linear regression. The results for the computed emotional stability and results measured from the Eysenck personality questionnaire are shown in Fig. 9. As shown in Fig. 9, The red bar is each subject's emotional stability derived from the questionnaire, while the blue bar is the emotional stability computed from the six affect features. Emotional stability is computed from the formula below:

$$Emotional\ Stablity = \alpha_0 + \alpha_1 F_{AV1} + \ldots + \alpha_6 F_{AV6} \tag{20}$$

where F_{AV1} to F_{AV6} are the six affect features. α_0 refers to the constant of emotional stability, while α_1 to α_6 are the coefficients of each feature. The constant and these coefficients are result from the linear regression to calculate the result

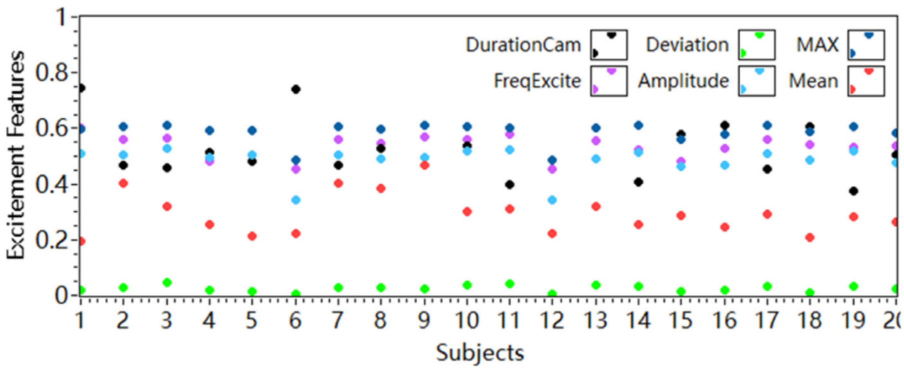

Fig. 8. Visualization of affect features from twenty subjects' excitement series.

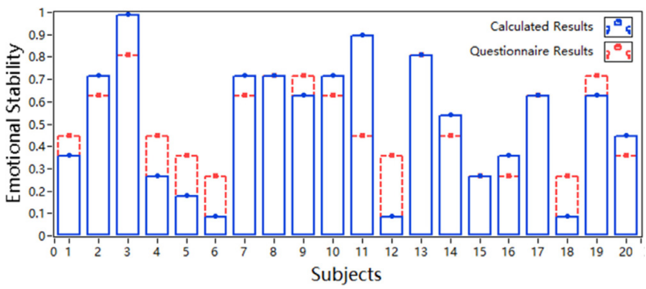

Fig. 9. Results of emotional stability (computed vs. measured from the questionnaire).

of emotional stability. Then, we verified the similarity between the computed results and the questionnaire results, which reached 79.6%.

5.4. Personal attention ability computing and analysis

The process of personal attention ability computing is represented below. Twenty subjects' focus features from their timely focus series data are extracted and displayed in Fig. 10.

Similar to the Figs. 8 and 10 shows six point sets which illustrate the six focus features of twenty subjects. Specifically, the horizontal axis refers to each of twenty subjects, while the vertical axis is the value for each focus feature. The range of timely focus data is [0, 1]. Hence, the features of maximum, mean, deviation, amplitude and frequency of excitement also ranges from 0 to 1, while the duration from focus to calmness is normalized by shortening it by a factor of 30 to fit the point sets. Attention ability computed from these features and measured from adult ADD questionnaire are illustrated below. Fig. 11 shows the results of twenty subjects' attention ability (range from 0 to 1) computed by their focus features and by the Jasper Adult ADD questionnaire by the linear regression. The blue bar and red bar represent the computed results and questionnaire results respectively. Attention ability is computed by the formula below:

$$Attention\ Ability = \beta_0 + \beta_1 F_{CV1} + \ldots + \beta_6 F_{CV6} \quad (21)$$

where, F_{CV1} to F_{CV6} are six cognition features. β_0 refers to the constant of attention ability, while β_1 to β_6 are the coefficients of each feature. The constant and these coefficients are the result from linear regression to calculate attention ability. Then, we verified the computed results and the questionnaire results, and found that the similarity reached 76.4%.

5.5. Relation analysis between personal emotional stability and attentionability

The relational characteristics between personal emotional stability and attention ability are computed. Specifically, three correlation analysis methods have been adopted for the analysis of these two characteristics, as shown in Figs. 12 and 13. Furthermore, we analyzed the correlation between male subjects and female subjects separately, and concluded their relational characteristics in emotional stability and attention ability.

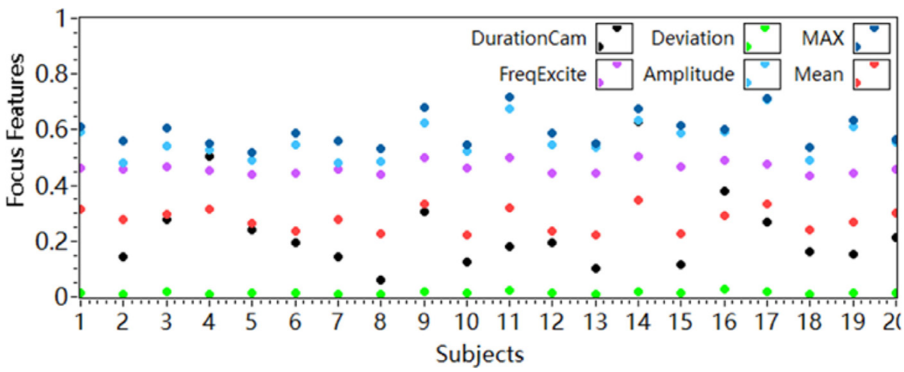

Fig. 10. Visualization of cognition features from twenty subjects' focus series.

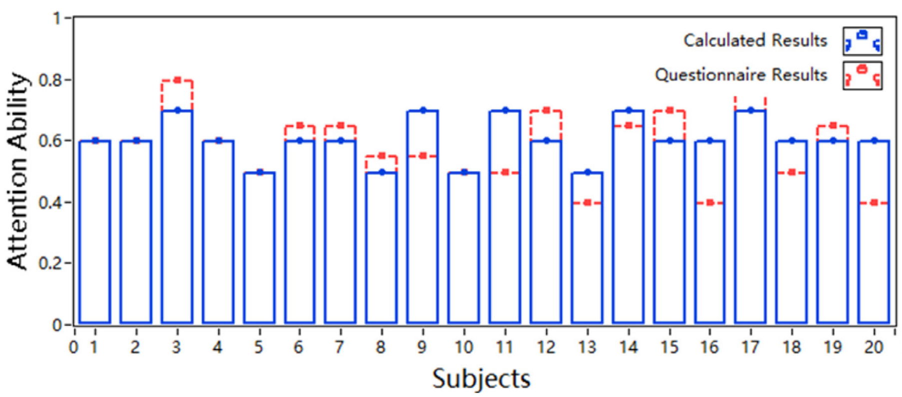

Fig. 11. Results of attention ability (computed vs. measured from the questionnaire).

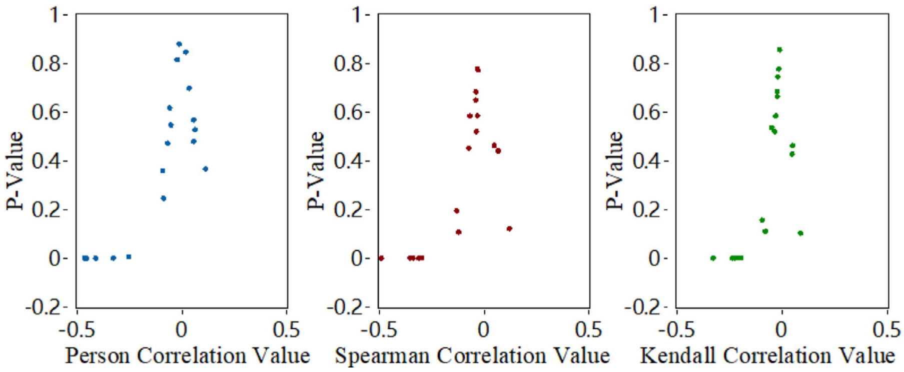

Fig. 12. Correlation between excitement mean & focus mean.

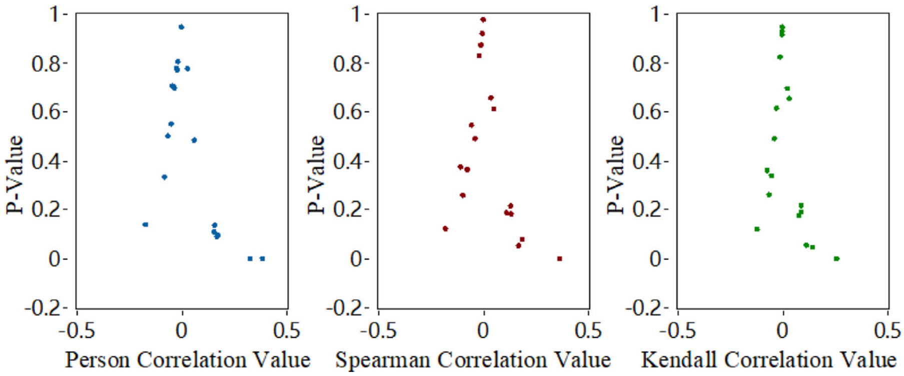

Fig. 13. Correlation between excitement deviation & focus deviation.

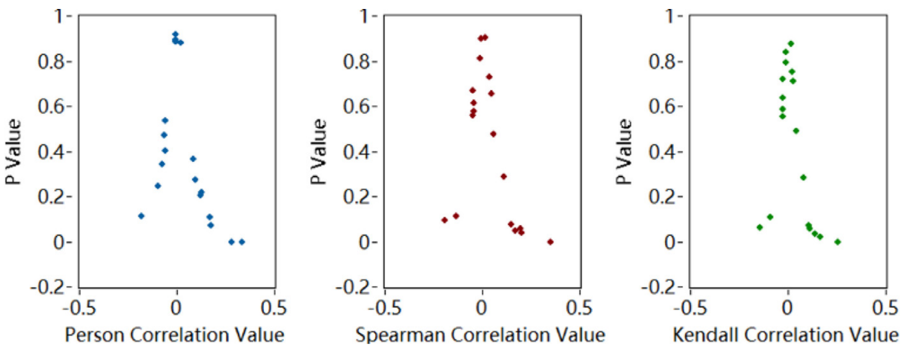

Fig. 14. Correlation between excitement mean & focus deviation (all subjects).

Fig. 12 illustrates the correlation between the mean of excitement and focus series every 20 s for the twenty subjects', while Fig. 13 represents the correlation between their deviation of excitement and focus series every 20 s. The three graphs from left to right shows the correlation result analysis by using Person, Spearman and Kendall correlation analysis, respectively. The horizontal axis is the correlation value indicating how much correlation there is between excitement and focus, while the vertical axis is the P-value indicates the significance of the calculated result. The node of each graph represents each subject. As shown in Figs. 12 and 13, the results according to each correlation analysis method are basically the same. For the mean of excitement and focus series, four subjects have a relatively high negative correlation (<-0.25) and low P-value (< 0.01) encapsulating the correlation between excitement and focus, while other subjects have no significant correlation between these two factors. For deviation in the excitement and focus series, only one subject has a relatively high positive correlation (> 0.4) and low P-value (< 0.01) disclosing the relationship between the fluctuation of excitement and focus. According to these results, we can conclude that four subjects would be inattentive when excited. In addition, one subject's fluctuation in emotions has a significant impact on his focus condition.

Figs. 14–16 illustrate the correlation between the mean of excitement and the deviation of focus for male subjects and female subjects, respectively. Each figure contains the results of correlation analysis based on Pearson, Spearman and Kendall

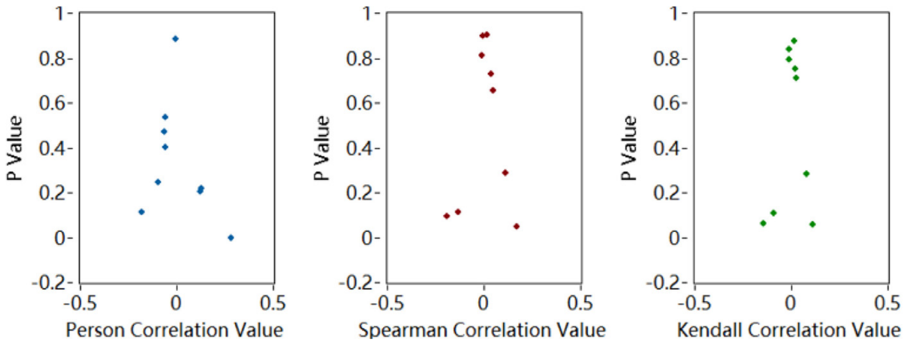

Fig. 15. Correlation between excitement mean & focus deviation (male subjects).

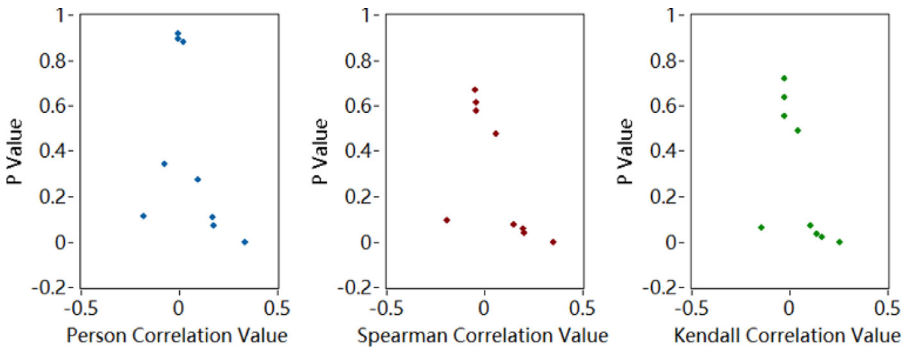

Fig. 16. Correlation between excitement mean & focus deviation (female subjects).

correlation analysis. The horizontal axis of these three figures and the vertical axis of Fig. 12 are the same with those of Fig. 13. The correlation with high P-value and low absolute correlation value is ignored, and Fig. 14 shows that people more strongly excited tend to have higher fluctuation in focus. Worse still, they might not concentrate under certain circumstances. Fig. 15 shows that only one male showed a high correlation between the mean of excitement and focus deviation. Fig. 16 shows that 4 females showed a high correlation between the mean of excitement and focus deviation. Hence, we conclude that, compared with males, females' focus fluctuation would be further disturbed by their strong affect. Therefore, there is individual difference in relational characteristics in regard to excitement and focus fluctuation.

6. Conclusions and future work

This research has focused on a general model of individual's characteristics, namely the Personal Character Model and its computing process. The Personal Character Model has been formulated through the work of a number of psychologists working on personality and consists of two kinds of characteristics. One kind are the characteristics of affect, behavior and cognition, and the others are the three pairs of relational characteristics between any two of affect, behavior and cognition. Furthermore, a general computing process of personal character model is illustrated in this research.

The experiment is not aimed at producing a comprehensive and accurate calculation of the Personal Character Model, but to clearly represent the elements of the Personal Character Model by personal character modeling process. Accordingly, three personal characteristics are calculated by following the model's computing process. Emotional stability and the ability to sustain attention were selected as one example of affect and cognition characteristics, respectively. The correlation between these two characteristics were selected as one of the relationships between affect and cognition. Each subject's results gleaned from a psychological questionnaire measuring emotional stability and the ability to sustain attention were selected for reference for the calculated results from the collected data. Both computed results show a relatively high degree of similarity (almost 80%) with the results from the psychological questionnaire, while the distribution of the correlation between each subject's emotional stability and ability to sustain attention shows differentiation between individuals based upon the relationship between affect and cognition.

Research into modeling personal character comprehensively and accurately is ongoing. So much work remains for further study in the following aspects. First, the personal character model has to be refined by reference to further related work, e.g., on personality. Secondly, the models' mathematical description has to be further refined. Third, more experiments should be conducted with more algorithms (in feature selection and fusion algorithms, and classification/regression algorithms) to verify further the rationality and feasibility of the proposed models.

Declaration of Competing Interest

The authors declared that they have no conflicts of interest to this work.

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