The "Onion Model of Human Factors": A Theoretical Framework for Cross-Cultural Design

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Abstract. Needs and preferences are two critical elements for starting a user-centered design. Nevertheless, there is a gap between the link of needs and preferences of user interface/experience. It is very difficult to find out why such a need could be transferred into a design preference. The exploration of dimensions in human factors could provide a theoretical foundation for the gap. Based on cultural "onion and iceberg" models and the dimensions of human factors, the present paper proposed the "onion model" of human factors as a framework to guide related activities of cross-cultural design. The dimensions from the core layer to the surface layer include motivation and preference, needs, values/beliefs/attitudes, identity (social role and self-image), cognition (from sensation to action selection), language, and behavior patterns. Besides the mentioned dimensions, emotion has an interaction across the layers. The distance between the center of a circle and the origin point of the "hidden" word shows the degree of the core. The core layers directly influence the nearest surface layer and indirectly influence the other surface layers. The onion model of human factors provides a theoretical framework for design-related activities, like evaluating existing interfaces in different cultures. The paper takes the differences of mobile apps in the U.S. and China as examples to illustrate that the onion model of human factors could provide the potential reasonable link between these differences and their possible explanations in a holistic perspective.

Keywords: Human factors · Onion model · Cross-cultural design · Mobile app

1 Introduction

Personas are important at the early stage of design and typically used to describe the user on a personal level, with their needs, preferences and habits [1]. They are also helpful to conduct user testing, evaluate new features, align with business strategy, facilitate analysis, and allow the product group to work at the same page [1, 2].

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But the method of personas has its limitations. The designers must commit themselves to the personas and trust in them to take fully advantage of them during the design process as there is a gap between the needs and the preference in design elements. For example, the methods to create a persona, such as interview or survey, are subjective and needs more expertise to support [3, 4]. Even the designers with rich experience think personas do not include enough information, and consequently would not be helpful in the design process [5]. Hence, it is necessary to propose an overall framework of human factors to guide the user-centered design process.

Moreover, personas are not suitable to be used in cross-cultural design. As we know, personas are created based on specific target group or small population levels [2, 4, 5]. But cross-cultural design generally would involve a large-scale population or group of persons, like different nations. So, a persona provides less information in cross-cultural design than in the situation personas were used in a traditional way. Some researchers have tried to use cultural models to get a link between cultural dimensions and interface differences among nations. For example, Singh and Matsuo [6] conducted a content analytic study of U.S. and Japanese web sites using the dimensions of Hofstede's cultural values to propose a framework as a guide for developing cultural congruent websites. Callahan [7] also analyzed the cultural differences and similarities in design of university websites from Malaysia, Austria, the United States, Ecuador, Japan, Sweden, Greece and Denmark based on Hofstede's model of cultural dimensions. But there's still a gap between the values of humans and using graphical elements.

Therefore, the present study aims to develop a holistic framework of human factors with multiple dimensions for cross-cultural design.

2 Human Factors in Culture

In terms of intercultural user interface design (IUID), Heimgärtner [8] proposed a toolbox for IUID consisting of the IUID method-mix, which provides a methodology to create the link between cultural dimensions and HCI dimensions as well as user interface characteristics. The IUID toolbox uses a hybrid approach integrating a combined use of the following concepts ("IUID Method-Mix" for short) to derive cultural HCI indicators relevant for the derivation of recommendations for IUID: HCI dimensions, cultural dimensions, intercultural variables, user interface characteristics, the culture dependent HCI model and finally the method of culture-oriented design. In the toolbox, Heimgärtner proposed the relationship between cultural dimensions (i.e. Hofstede's model of cultural dimensions: individualism vs. collectivism, uncertainty avoidance, long term orientation and masculinity vs. femininity [9]) and HCI dimensions (i.e. information density, information frequency, interaction speed and frequency [10]). Heimgärtner stated the cultural dimensions alone are too rough for intercultural user interface design and additional cultural variables are necessary to be included in a theoretical framework for IUID.

2.1 Models of Cultural Dimensions

In the past many different studies are conducted to show how national culture influences information systems [11]. The different cultural models are clustered into three types based on the amount of cultural dimensions taken into account: historical-social models, single, and multiple dimension models are used in the literature [12]. Historical-social models evaluate cultures based on historical evolution and social heritage at a regional level. Single dimension models categorize cultures into one dimension with two contradicting values. For example, these values can be low and high context [13, 14], or polymorphic and monochromic [15]. In contrast to single dimension models, the multiply dimensions' models consider more than one facet of a culture, as for instance the six-dimensions' model of Hofstede.

Hofstede's Six-Dimension Model. In terms of values and attitudes, Hofstede's cultural model has been widely accepted by researchers and practitioners [16–18]. The model consists of the following six cultural dimensions: power distance, individualism, masculinity, uncertainty avoidance, long-term orientation and indulgence [9, 19, 20]. Each country is graded within these six dimensions with values ranging from 0 to 100. The higher the number, the more the characteristics described by the dimension is true for a culture.

Power Distance (PD): acceptance of class differences in a particular culture.

Individualism (vs. collectivism): the degree to which individuals feel they are "on their own" rather than part of a larger group identity.

Masculinity (vs. Feminist): the degree to which a culture emphasizes competition, achievement, and "getting ahead".

Uncertainty avoidance (UA): intolerance for ambiguity and risk.

Long term orientation (vs. short term orientation): the degree to which a culture focuses on the future.

Hofstede [19] and Cyr [21] both found Chinese and German had significant scores on power distance, individualism, and has a slight difference on indulgence. Uncertainty avoidance, long-term orientation and indulgence are just significant in one of the two studies.

Hall's Single Dimension Model. Hall [13, 14] defines culture as the way of life of a people: the sum of their learned behavior patterns, attitudes and material things. Hall stated the categorization of culture into high context versus low context cultures to understand their basic differences in communication style in different cultures. Researcher stated that individualism-collectivism has a direct effect and an indirect effect via self-construal on communication style - especially self-construal predicts the communication style better [22]. A person with independent self in an individualistic culture uses low-context communication, focusing more on self or topic itself, whereas a person with interdependent self-construal in a collectivistic culture applies high-context communication.

High context communication is implicit, indirect, ambiguous, harmonious, reserved and understated, which involves more of the information in the physical context or internalized in the person, which provides greater confidence in nonverbal clues of communication than the verbal aspects [13, 14, 22]. This is typical in Asian countries and reactive cultures.

Low context communication is explicitly stated through direct and precise language based on true intentions [13, 14, 22], which is typical in German-speaking countries and linear-active cultures [23]. Moreover, members from linear-active cultures are factual and decisive planners who are task-oriented, highly organized and prefer doing one thing at a time, termed monochronic [24]. In monochronic cultures, people take time commitments (deadlines, schedules) seriously, and they adhere strictly to plans [25].

In contrast, members of reactive cultures would like to be courteous, outwardly amiable, are accommodating and compromising, use silence and thinking in silence and are good listeners who combine their own and other's opinions. People from reactive cultures rather like to do multiple tasks at a time, termed polychronic [24]. People from polychronic cultures rank personal involvement and completion of tasks above the demands of the pre-set schedules, and they change plans often and easily, and have a more relaxed approach to punctuality [25].

2.2 Iceberg Model of Human Competence

Two prominent ways to illustrate the concept of culture are the onion model (see Fig. 1a) and the iceberg model (see Fig. 1b) [26–29]. The onion model is used to show the depth of different ways to embody culture. The inner layer is more invisible than the outer layers.

As to the iceberg model, the competence model from individual perspective could provide a detailed description about the stratified representation of culture-related dimensions in human factors. Human factors design is understanding human capabilities or limitations and applying this knowledge to system or interface design. Therefore, it is necessary to learn about the human competence model to get insights into the framework of human capabilities.

McClelland, the father of the competency movement, introduced the competency approach to describe the characteristics underlying superior performance [27, 28]. He compared competencies to an iceberg with motives, traits, self-image, values, attitudes and social role, knowledge, and behavior (see Fig. 1b). Behavior, knowledge and skills are at the tip of iceberg, which are more observable. Values, attitudes, social roles, self-image, traits, and motives are the underlying elements, which are not easy to identify. Hence, the iceberg model of human competence overlaps with the onion model of culture, see Fig. 1a [19, 26, 29].

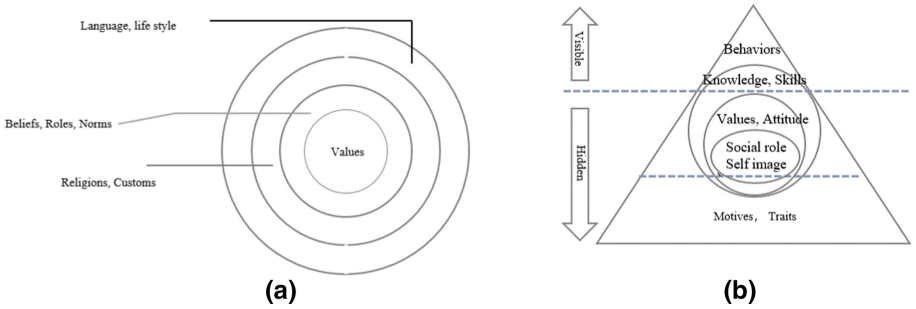


Fig. 1. The onion model of culture (a, left) and the iceberg model of human competence (b, right)

3 The Onion Model of Human Factors in Culture

Human factors are the applications of psychological and physiological principles to the engineering and design of products, processes, and systems [30] to make people use system or machine efficiently, safely, and comfortably. Human factors involve human cognition, emotion, and behavior patterns [31] as well as physiological and biomechanical characteristics related to physical activity [32]. Cognition includes consciousness, imagination, perception, thinking, judgement, language, and memory. Combined with the onion model and iceberg model of culture, the "onion model of human factors" was developed in the present study, see Fig. 2. The concepts in the onion model of human factors and their relationships are described in this paper based on the literature review.

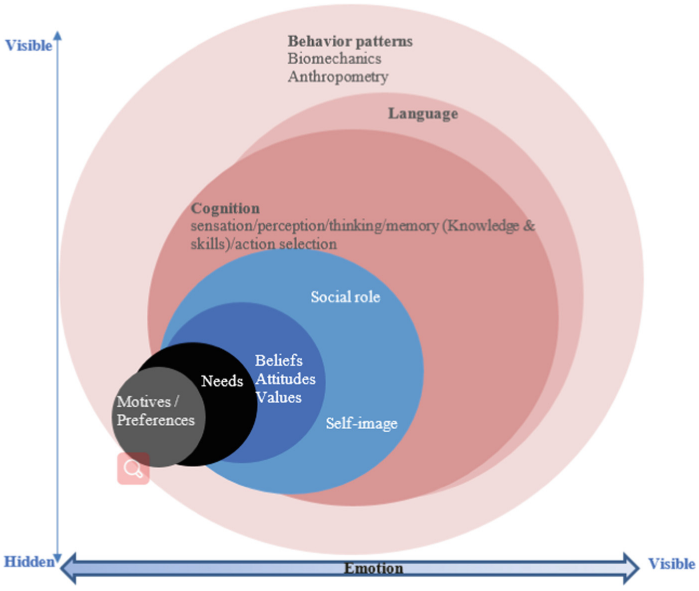


Fig. 2. The onion model of human factors

The dimensions from the core layer to the surface layer include motivation and preference, needs, values/beliefs/attitudes, identity (social role and self-image), cognition (from sensation to action selection), language, and behavior patterns. Besides the mentioned dimensions, emotion has an interaction across all layers (see the Fig. 2). The distance between the center of a circle and the origin point of the "hidden" word shows the degree of core: the closer the distance of a layer away from the origin point labeled hidden is, the more core and important the concept of layer is. The more core layers have a direct effect on the layer closest to it and indirect effects on the remaining outer layers.

3.1 Motivation/Preferences and Needs

Motivation and preferences are at the same level, the most core level. Motivation is willingness of action or behavior, including need-based motivation [33, 34] and reward-based motivation that is related to emotion [35]. Preference is the selection of one thing or person over others. It is akin to the notion of want. The thing or object a human prefer is something that he/she desires to have, whether he/she needs it. Some preferences are related to goals or intentions, which are conscious. But some are unconscious human experiences, which are influenced by culture.

The next layer is needs as motivation includes a need-based motivation, and some preferences are related to goals or intentions. Needs are related to how live a recognizably human life. The thing or object of a human need is something, which he/she must have in their life, involving basic needs and psychological needs. Needs are influenced by culture and responsible for most of the behavior.

The relationship between motives/preferences and needs is shown in Fig. 3. Psychological needs and some unconscious human preferences related to reward-based or emotion-based motivation are influenced by culture. For example, culture shapes people's preferences for approach versus avoidance motivation. Approach motivation is that the energization or the direction of behavior was motived by positive stimuli (i.e. gain); whereas avoidance motivation is that the energization or direction of behavior was triggered by negative stimuli (i.e. loss). Chinese or Japanese prefer avoidance goals while people in German or US prefer approach goals [36, 37]. Americans were better at recalling positive events that either had or had not been happened (e.g., I found a 20-dollar bill? Or the movie I wanted to watch was not playing anymore?), whereas Japanese were better at recalling negative events that had or had not been happened (e.g., I found a zit on my nose? Or my least favorite class got cancelled).

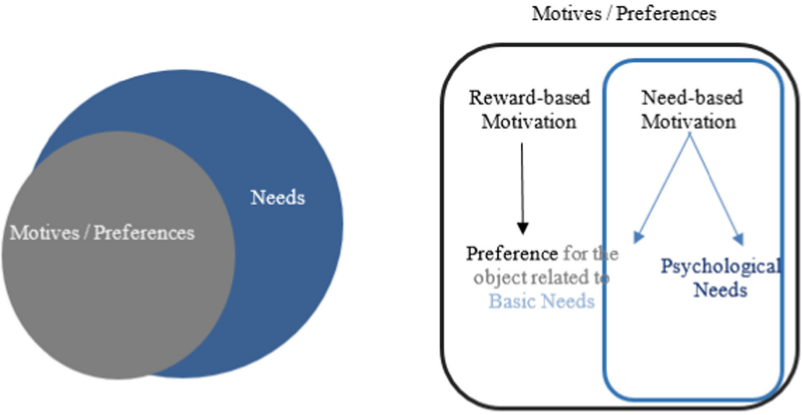


Fig. 3. The onion part (left) and the scale part (right) of motivation and needs

3.2 Values and Identity

Values are enduring beliefs that a specific mode of conduct/behavior is personally or socially preferable to an opposite mode of conduct/behavior, i.e., family, successful career, money, power, wisdom, love, skill, morality, and pleasure, which are influenced by culture.

Meaning in life or purpose is related to values and motivations [38]. Sometimes an individual is motivated by his/her values to achieve a sense of meaning in life. Values and needs are also closely linked and have an overlap [39]. Needs are basic, dynamic and contextual, while values are long-term oriented and core. In consciousness, values guide a person's psychological needs. As needs are filled for an individual but values are fulfilled by the individual, values are more close to choice, action, and behavior [40]. We can use our values to guide us in making choices about the most meaningful ways of having our needs met.

Identity is the term what and how an individual thinks about himself/herself, the sum of our knowledge and understanding of ourselves, including self-identity (i.e., self-image) and social identity (i.e., social roles). It is influenced by values. Carl Rogers [41], a humanistic psychologist, states that self-image is the view we have of ourselves, like independent self and interdependent self [42]. Chinese are more likely to think themselves as interdependent self, while people in Western countries are independent selves. Social roles are how we see ourselves in society (i.e., parent, son, friends, student, teacher), which affects what we think, we should do in a particular role, and the things that we consider to be important. So, the common values, attitudes, and beliefs have an influence on the individual's identity. Self-image and social roles are a powerful driver of cognition and behavior [43]. Therefore, its layer is located at the one between values/beliefs/attitudes and cognition. The relationships among needs, values, and identity are shown in Fig. 4.

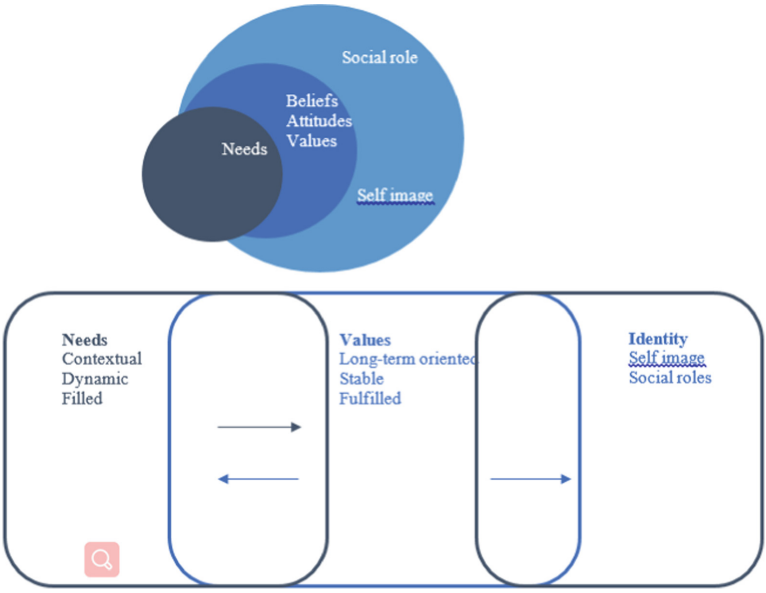


Fig. 4. The onion part (top) and the scale part (bottom) of needs, values, and identity

3.3 Cognition, Language and Behavior

Values and identity influence the cognitive or psychological processing. Cognition is a term referring to the mental processes involved in gaining knowledge and comprehension. It contains attention, perception, memory, thinking, decision-making, learning, and language [44, 45]. The theory of cognitive dissonance [46] proposes that people have a motivational drive to reduce the dissonance by changing, justifying, or rationalizing their attitudes, beliefs, and behaviors. Therefore, cognition is between values/beliefs/attitudes, and behavior, and based on the layer of identity. Cognition is finally located at the layer between identity and behavior (see Fig. 5). And, also cognition and communication style is influenced by culture. For example, Asians tend to engage in context-dependent and holistic perceptual processes by attending to the relationship between the object and the context in which the object is located, while Westerners tend to engage in context-independent and analytic perceptual processes by focusing on a salient object independently of its context [47]. Chinese prefer high-context communication, but people in Western countries prefer low-context communication [13, 14]. The study of Rau et al. [48] showed that Chinese individuals preferred and trusted the implicit style and were more likely to accept the implicit recommendations, while German preferred and trusted the explicit style and were more likely to accept the explicit recommendations.

Language concerns about descriptions of abstract thoughts, situations, objects, and sounds. The interaction between language and cognition remains an unsolved scientific challenge. But it is sure that they are linked to each other. Language helps us to develop cognition, but cognition does not entirely rely on language as evidenced by hearing-disabled persons [49]. Language is a communication tool, which transmits cultural knowledge and influences social behavior [50]. It is implicated in most of the

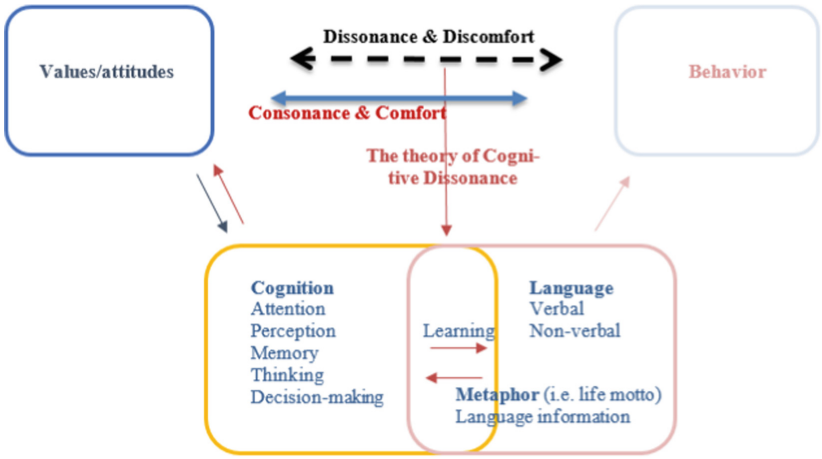


Fig. 5. The relationship among values/attitudes, cognition, language, and behavior

phenomena that lie at the core of social psychology: attitude change, social perception, personal identity, social interaction, intergroup bias and stereotyping, attribution, and so on.

Emotion is a conscious and unconscious mental reaction subjectively experienced as strong feeling usually directed towards a specific object/thing/person and typically accompanied by physiological and behavioral changes in the body. It is associated with thoughts, feelings, and behavioral responses. It is across the whole process ranging from motivation to behavior and mutual interaction with and within the whole process. For example, the sound of music drives us emotionally, and emotion reversely influences the choice of music songs [49]. Emotion is also culturally influenced. For instance, Frijda & Sundararajan [51] stated harmony-based savoring as a unique Chinese emotion.

4 The Application of Onion Model of Human Factors

The implication of the onion model of human factors is that it provides potential or even verified explanations for cross-cultural design. Here we take the interface differences of mobile apps in China and in the US as examples to illustrate how to propose explanations for the differences. We used the IUID mixed method to find the examples of cultural differences in mobile app design, including apps for maps, music, shopping, service, and communication in China and in the US.

4.1 Scenario-Based vs. Function-Based Design

Both mobile map and service apps show that mobile apps in China are designed based on scenarios or contexts whereas those in US are designed based on functions or attributes (see Fig. 6). For example, Baidu map and AutoNavi map in China provide covid-19 info (i.e., numbers of cases and the update regulation or notification) on the main page of the map. Google map has not included the related info on the main page at all. Besides this

difference, map apps in China use the scenario (i.e., Commuting scenario) to be as the label of menu items, which does not occur in American map apps.

According to user interface elements identified by Marcus [17], this kind of difference belongs to the mental model dimension, which is related to categories in human cognition. In terms of the onion model of human factor, these UI elements are related to attention, perception, and memory parts, which are embodied by cognitive style. Nisbett [47] found that Chinese tend to put relevant activities together (holistic thinking) whereas Western users are likely to concentrate on completing specific activities individually (analytic thinking). In terms of the relationships of the layers, we could link the difference in cognitive style to that in motivation, need, and values as these three dimensions have direct and indirect effects on cognitive style. Chinese preference for holistic thinking is related to avoidance loss in motivation, relatedness need, and collectivism and long-term orientation values [53]. Avoidance loss, especially loss of face, make people be more concerned about others (i.e. needs and judgements), and finally cultivate the relatedness need and more collectivistic culture within a group. People with holistic thinking are more likely to have the high-context communication and polychromic time management style. But approach goal or benefits in motivation, autonomy need, individualism and short-term orientation, low-context communication, and monochromic time management style are related to analytic thinking.

Hence, our model provides more detailed information to help designers or practitioners to understand why there is such a difference (see Fig. 6). It is more concrete than persona-based approach, and could help researchers to find specific evidence by literature review in terms of these dimensions and their features and form a hypothesis even though there is no related study on the needed topics.

Fig. 6. Different user interface characteristics of map apps in China (the two left) and in the US (the one right)

4.2 Strong Social Connection Design in China

Map, music, and service apps in China would like to make user have a strong social connection with friends and strangers (i.e., nearby) by gamification (i.e., ranking). For example, Fig. 7 shows that the AutoNavi map app displays the info "You defeated 5.2% of users!", but Google map shows "let friends know where you are" and does not involve the info of unknown users. It is related to the avoidance loss (face is important, I cannot lose my face), status self-identify need, power distance value, high context, and harmony-based savoring emotion. Ranking could realize the user's status self-identity

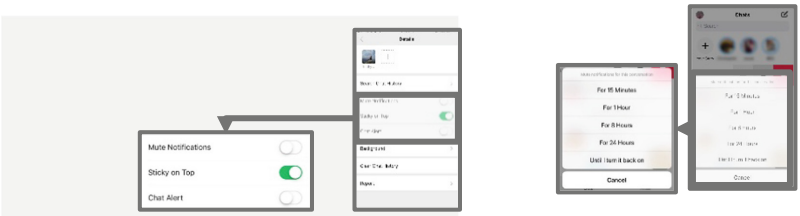
needs and power distance value. It is gamified not in a real world, which would align with the Chinese preference for harmony-based savoring in high context communication. They need to pay attention to the balance of others and themselves as Chinese are interdependent self-construal and their thoughts, feelings, and motivations are embedded in relationships and in specific context, settings, and roles [42].

AutoNavi Map Google Map

Fig. 7. The difference between AutoNavi map and Google map in the social connection by gamification

4.3 Passive Error-Tolerance Interaction vs. Proactive Error Avoidance

Mobile apps in China show a simple setting choice, whereas mobile apps in the US provide multiple choices for setting a feature. For example, Fig. 8 shows WeChat, a communication app in China, just enabling binary choices for setting a feature, like either "on" or "off". In contrast, Messenger provides five choices for users to complete their settings. This is related to error or risk tolerance. In the onion model of human factors, it is corresponding to low uncertainty avoidance in China but high uncertainty avoidance in Western cultures. It is also related to security needs. It might be different requirements to satisfy the security needs for Chinese and American users. Sauer, Mertens, Groß, Heitland, and Nitsch [52] found that Chinese trust passive safety more than Americans.



WeChat Messenger

Fig. 8. The differences in setting up a feature in WeChat and in Messenger

5 Conclusion

The onion model of human factors provides a holistic framework for cross-cultural design. The dimensions from the core to the surface layer include motivation and preference, needs, values/beliefs/attitudes, identity (social role and self-image), cognition (from sensation to action selection), language, and behavior patterns. Besides the mentioned dimensions, emotion comes into play across the layers. The multiple dimensions related to culture and the relationship among the dimensions in the onion model of human factors allows researchers, designers and practitioners to gather more detailed information for further research or deriving reasonable activities for intercultural user interface design as it provides theoretical explanations for cross-cultural differences.

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