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Tracking the Temporal Dynamics of Cultural Perceptual Diversity in Visual Information Processing

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Summary

Human perception and cognition processing are not universal. Culture and experience markedly modulate visual information sampling in humans. Cross-cultural studies comparing between Western Caucasians (WCs) and East Asians (EAs) have shown cultural differences in behaviour and neural activities in regarding to perception and cognition. Particularly, a number of studies suggest a local perceptual bias for Westerners (WCs) and a global bias for Easterners (EAs): WCs perceive most efficiently the salient information in the focal object; as a contrast EAs are biased toward the information in the background. Such visual processing bias has been observed in a wide range of tasks and stimuli. However, the underlying neural mechanisms of such perceptual tunings, especially the temporal dynamic of different information coding, have yet to be clarified.

Here, in the first two experiments I focus on the perceptual function of the diverse eye movement strategies between WCs and EAs. Human observers engage in different eye movement strategies to gather facial information: WCs preferentially fixate on the eyes and mouth, whereas EAs allocate their gaze relatively more on the center of the face. By employing a fixational eye movement paradigm in Study 1 and electroencephalographic (EEG) recording in study 2, the results confirm the cultural differences in spatial-frequency information tuning and suggest the different perceptual functions of preferred eye movement pattern as a function of culture. The third study makes use of EEG adaptation and hierarchical visual stimulus to access the cultural tuning in global/local processing. Culture diversity driven by selective attention is revealed in the early sensory stage.

The results here together showed the temporal dynamic of cultural perceptual diversity. Cultural distinctions in the early time course are driven by selective attention to global information in EAs, whereas late effects are modulated by detail processing of local information in WC observers.

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1 Introduction

During my high school year, a collection of 20th century architecture in my hometown was designated by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as a World Cultural Heritage Site. Now known as the “Kaiping Diaolou and Villages”, it is a group of multi-storeyed watchtowers mainly built with financial support from the villagers who travelled abroad, mostly in South Asia and North America. Each of them is a combination of Chinese and Western architectural styles in rather unique manner. At the time, this was quite a significant event for a small southern Chinese city like my hometown. The local government offered a free tour to all students as a general education session. Growing up around these old buildings, I was actually amazed by the stories behind all the old stones and sculptures: how my ancestors began to construct these thick walls to fight against frequent heavy floods and bandits; how the older generation struggled to survive in a foreign land, yet still were tied to their roots; how these buildings underwent attack from guns and cannons and are still standing… It was the first time I encountered the concept of “culture”, and truly experienced its meaning.

A couple of years later, I moved to a big city for my undergraduate course, and started to travel around. Meeting people from different places, I slowly realised that culture is more than old buildings and what people do during festivals. Culture is in the food we eat, in the clothes we wear, and more importantly, in those things we cannot physically see: language, religion, values, social conventions, etc. These differences even exist in regular daily interaction. I am still surprised at how people react to a similar situation, so distinctly dependent on their cultural background.

The differences extend even further. For almost a century, social scientists such as anthropologists and social psychologists have examined how culturally specific activities and cultural practice shape individuals’ responses to social information. During the last 20 years, researchers in cognitive science and neuroscience have discovered that culture even impacts on basic cognitive process, such as attention and visual perception. These results are surprisingly contradictory to the universal assumptions of low-level information processing (Nisbett et al. 2001).

Built upon the previous findings of cultural diversity in visual perception, the work I have undertaken during my Ph.D. aims to investigate when and how culture affects information processing. Given the complexity of the concept “Culture” and its ambiguity among different research domains, the opening pages of my thesis will specify the meaning of culture being applied in all the studies. In the first section, I will discuss the definition of culture and its distinction with regard to race and nationality. A review of the behavioural and neuroimaging data on cultural differences in social values and high-level social cognition will follow. In the third section, I will summaries cultural modulation in attention and perception, according to various visual categories. Specifically, theoretical frameworks including individualist-collectivistic dichotomy, independent-interdependent self-construal, and analytic-holistic cognitive style will be discussed in the introduction. A brief section on the methods employed throughout this work (i.e. electroencephalogram and fixational eye movement) will precede the original empirical studies included in this thesis.

1.1 Culture: A dynamic Concept

Preamble

Here in the opening chapter, I will discuss some key incongruities in the definition of culture. After conceptualizing the core foundations of culture, I will provide my own definition. The distinction between culture and nationality, race would also be discussed.

1.1.1 Define Culture

Culture as a concept is essential in daily human life and scientific practice. It has been widely used in popular expression, such as “corporate culture”, “Hip-hop culture,” or “preserve our culture and traditions”. Besides public discourse, we often hear it in a political context. For instance, it is widely used in policies involving immigration or minorities, as it usually triggers strong emotions (Fox and King 2002). Moreover, culture has been an important concept in many academic fields. It has been studied in many domains including anthropology, sociology, the humanities, linguistics, psychology and other social sciences. For example, culture is considered as the core concept of anthropology (Fox and King 2002; Kroeber and Kluckhohn 1952).

English anthropologist Edward B. Tylor gave the very first definition of human culture in modern social science (Tylor 1871). As he wrote in the opening of *Primitive Culture*, in 1871: “*Culture*, or *Civilization*, taken in its wide ethnographic sense, is that complex whole that includes knowledge, belief, art, morals, law, custom, and any other capabilities and habits acquired by man as a member of society.” However, after being studied in various fields for nearly 150 years, culture is still an amorphous concept with little consensus across or even within research domains (Kroeber and Kluckhohn 1952). For example, Kroeber & Kluckhohn (1952) listed over 160 definitions of *culture* with little overlapping emphases.

There is a number of primary divergences of the definition and the usage of the concept of *culture* in social science (Fox and King 2002; Wyer et al. 2009). One of the main difficulties is that a broad range of social activities and phenomena can be considered as “cultural”. For example, definitions similar to E. B. Taylor’s took an inclusive approach that includes both the material worlds (such as products, technology, and social activities) and the internal status (e.g. symbols, beliefs, and ideas). Other definitions tend to focus on ideational factors only, such as values and representation. For instance, Goodenough (1957) defined *culture* as “whatever it is one has to know or believe in order to operate in a manner acceptable to [society’s] members”. Overall, the disagreements on the definition of *culture* could be summarized as the following: 1) whether *culture* is a static entity according to circumscribed geographic boundaries (i.e., Hofstede 1984; Hofstede and Hofstede 2001; LeVine 2001) or a dynamic, changing character (i.e., Hong and Chiu 2001; Hong et al. 2000; Oyserman and Sorensen 2009; Tsui et al. 2009); 2) whether *culture* should be conceptualised as a whole (i.e., Bond and Leung 2009; Schwartz 1992; Schwartz 2009) or as a collection of concepts or knowledge (i.e., Chiu and Hong 2007; Oyserman and Sorensen 2009; Triandis 2001, 2009); 3) whether *culture* exists outside of the individual in a social environment (i.e., Bond and Leung 2009; Hong and Mallorie 2004; Schwartz 1992; Schwartz 2009) or is located in the individual's mind and actions (i.e., Wan and Chiu 2009).

Despite these discrepancies in regarding to the properties of *culture*, psychologists can generally agree upon two initial assumptions (Han et al. 2013). Firstly, there are similarities among a group of individuals, which are not part of their innate biological condition (Murdock 1932; Nisbett 1990). These mutual characteristics have developed over thousands of years within a given cultural group, and have become the core content of *culture*. The general features among cultural members can be internal (e.g. knowledge) or external (e.g. social behaviour). Some theories focus on the internal properties. For example, Keesing (1981) characterised *culture* as a shared system of competence consisting of people's "theory of what [their] fellows know, believe and mean, of the code being followed, the game being played". Similarly, Hong suggested that members from the same culture share networks of knowledge (meanings, routines of thinking, and the way of interacting with others), which are crucial for communication (Barth 2002; Chiu and Hong 2007; Hong 2009; Hong and Chiu 2001). Other perspectives took a more general approach and considered both internal and external features. For example, some social scientists defined *culture* as people's shared representations of reality that include customs, values, beliefs, behavioural scripts, daily interaction, social convention and institutions (Pelto and Pelto 1975; Romney et al. 1996). Moreover, few cultural psychologists further defined *culture* operationally as statistical norms of the shared internal features. For example, few theories considered the average personal characteristics such as values, beliefs, and personal attributes as *culture* (Wan and Chiu 2009).

Importantly, these shared meanings or information are distinguishable among cultures. Thus, they can be valuable delimiters to effectively distinguish one group from another, creating what has been referred to as cultural speciation (Goodall and Berman 1999).

The second initial assumption is that the shared cultural features transmit from one individual to another, non-genetically, through social learning (Kashima 2009; Kashima et al. 2008). Humans are born without predisposition to any particular culture, but rather have the potential and capability to acquire, and even to create culture (Harris 1999). In this sense, individual development could be viewed as a process of obtaining and embodying cultural belief systems or behaviour patterns from their surroundings (Rogoff 2003). From the very beginning of their lives, people engage in the complex composition of materials and social rules or practices, as well as folk beliefs, of their respective local communities. As suggested by Han et al. (2013), people adjust their value system and adapt their behaviour to meet the standards of the society. Such cultural knowledge development might even change the brain structurally and functionally, to become closely attuned to the surrounding socio-cultural environment (Wexler 2006).

The assumption that cultural knowledge is socially transmitted has a crucial effect in psychology and cultural neuroscience research. Firstly, people from the same cultural groups can be quite heterogeneous in terms of the values and beliefs they acquire. Secondly, an individual may change his/her cultural values and beliefs as a result of experience (such as emigrating from his/her native country). This is particularly true in contemporary societies, where cultural exchanges occur often and rapidly. People in modern societies are usually exposed, sometimes deeply, to other cultures' practices and beliefs in multiple socio-cultural contexts. Multiple cultural systems may become part of any single individual. At times this may require an individual to switch to and fro between different cultural systems during interactions, depending on particular contexts of social encounters (Hong et al. 2000). As for researches sampling participants from different cultures, it is important to limit the confusion caused by multi-cultural experience. For example, some studies used questionnaires to select participants with minimal experience of other cultures (Jack et al. 2012b).

In summary, there are similarities among individuals within a geographically isolated area. These internal similarities are independent of human biological conditions, and represent a dynamic concept of the socio-cultural environment. They are developed over a long period of time in a society, and acquired by the individual through social learning. Moreover, these internal features interact with the external environment to create a complex and dynamic social atmosphere where cultural information can be transmitted.

It is worth noting that both assumptions are taken from a subjective perspective. While some researchers took this perspective and defined *culture* directly as a set of shared values or knowledge systems (e.g., Hong and Chiu 2001), other theories tended to see culture as the external environment where such internal similarities are developed (e.g., Han et al. 2013). The opinion on whether such subjective cultural information should be the main body of culture deeply influences the methodology and the approaches chosen during experiments. As summarised by Kashima (2009), cultural researchers who focus on internal properties usually consider *culture* as a mediator, or something that could/should be manipulated. Such approaches either actively change the "level" of cultural value through social priming (i.e., culture priming research), or using questionnaires to measure cultural values as mediating variables (e.g., Hong et al. 2000; Kühnen and Oyserman 2002; Trafimow et al. 1991). As an alternative, approaches that hold an external view compare individuals from different cultures – mainly between Western Caucasian and East Asian - in beliefs, attitudes, and values as well as associated social behaviour (e.g., Leung and Bond 2004; Leung et al. 2002; Schwartz 1992; Schwartz 1994; Triandis 1995). In these so-called cross-cultural studies, culture is usually being controlled as an independent variable. Such approaches are more closely related to "natural science"- like (Kashima 2009).

Despite the aforementioned differences in perspective and the absence of a genuine definition of culture, a general practice in culture studies has long been established. Indeed, by conceptualizing how an individual relates to the in-group and out-groups, a unique social characteristic could be identified in one and the same cultural population. Such characteristic could be related to some distinctive sensorimotor tendencies (e.g., the span of visual attention, biases in cognition and categorization, styles of learning) under prevailing condition. Importantly, the cultural profile of the group is usually defined by the conceptualized social aspects, with the sensorimotor behaviour biases being treated as the effect of culture on cognition (e.g., Nisbett and Miyamoto 2005; Norenzayan et al. 2002; Varnum et al. 2010). While research subjects such as in sociology and anthropology aim to characterize given societies into different cultures, the primary object of cultural psychology or culture neuroscience is to investigate how these high-level social-cultural characteristics influence the configurations of perception and cognition, and how they further shape internalized behaviour patterns and other mental functions. Importantly, the fundamental of cognitive processes might not be reliably identified on the basis of research and theory that are developed within a single social context (Wyer 2009). By comparing observers sampled from one culture to others, researchers can distinguish to what extent such configurations should be considered to be fundamental.

In the current thesis, I took the same approach as cross-cultural research. Cultural differences in human mental processes and underlying cognitive mechanisms have been investigated extensively under this approach in the past two decades. From this line of research, theoretical frameworks such as individualistic versus collectivistic values, independent self-construals versus interdependent self-construals, and analytic versus holistic cognitive tendencies have emerged to guide empirical studies of cultural discrepancy in human perception, cognition and emotion (Kitayama and Cohen 2010; Nisbett et al. 2001; Varnum et al. 2010). Such theoretical frameworks will be discussed in the next two chapters. Cultural psychology takes the view that human cognitive and affective processing varies as a function of cultural environments. These diverse environments provide unique social contexts in which psychological processes are developed (Kitayama and Uskul 2011). The findings of cultural psychological research stimulate researchers to investigate neural substrates of the cultural diversity of human cognition and emotion.

Therefore, here I define *culture* as a complex and dynamic external social-visual environment in which the human value system and the human brain is fostered and shaped. From a neuroscience point of view, such a definition emphasises the socio-cultural nature of the human brain and places great weight on the influence of cultural values, beliefs, and practices shared by a social group on functional organization of the human brain. In addition, I included the visual environment as a major similarity among individuals. As I will explain in the next two chapters, the cognitive modulation effect of culture might not only come from social experiences, but also from visual experience that shapes our perception tuning to different information.

Previous cross-cultural studies assessed cultural differences in human cognition by comparing the behavioural performances and the neural activities between Western Caucasians (Europeans and North Americans) and East Asians (Chinese, Japanese and

Koreans). Although there is of course no such thing as a homogeneous ‘Western’ or ‘East Asian’ culture, Western and East Asian societies nevertheless differ in many aspects, and provide good samples for psychologists to investigate cultural differences in human cognition (Han and Northoff 2008). However, individuals from Western culture or East Asian culture also have different nationalities and races. In the next part, I will provide a belief distinction between them. Other issues related to such dual-cultural sampling will be discussed in the last chapter of the current thesis.

1.1.2 Culture, Nationality and Race

Nationality is defined by social group membership, based on a shared nation state of origin. Different from the term *culture*, which emphasises shared ideas, values, beliefs, and practices, people of the same *nationality* do not necessarily share the same beliefs, values, or practices. Majority of cross-cultural psychology studies have recruited subjects from two different cultural groups (e.g., Westerners and East Asians) on the assumption that the two groups differ in specific cultural values or specific cognitive processes (Han and Northoff 2009). While these different cultural group members usually have various nationalities, in some case they can be from a same nation as well. For example, a number of cultural psychology studies have investigated cultural groups who are from the same nation, but are defined by ethnic, religious or political beliefs (Han et al. 2010; Han et al. 2008). In such cases, two groups of participants share the same nationality and language but differ only in a set of shared beliefs/values and practices, which are hypothesised to be relevant to a particular pattern of neural activity.

Humankind can be divided into different races by distinct physical characteristics such as skin tone, facial feature or body shape. Individuals from a same racial group usually are similar in various fixed and biologically determined psychological traits and tendencies. Unlike *culture*, *race* is predetermined by inherent biological basis and unchanged over the course of a lifespan (Young 1994). Moreover, individuals classified as belonging to the same race do not necessarily share the same cultural values and experiences. For example, native Chinese and British-born Chinese may be considered as belong to the same racial group, but they do not share the same cultural values and beliefs. Researches focus on *race*, such as in empathy or face recognition, have distinctive different assumptions and results compare to studies on culture. For example, they tend to find similar cognitive pattern and neurocircuitry towards in-group or out-group between different races (Kubota et al. 2012).

In summary, *culture* can be separated from *nationality* and *race*. Although cultural psychology and cultural neuroscience studies sample participants from different cultures who usually also belong to different nationalities and races, the hypothesis and independent variables are dissimilar to those studies focusing on *nationality* or *race*.

1.2 Social Differences among Cultures: Individualism and Collectivism

Preamble

As explained in the opening chapter, culture should be considered as a unique combination of environmental factors where specific knowledge could be transferred. One example is the value in regarding the individual in relation to society. Following Hofstede's cultural dimensions theory, individualist vs. collectivistic values are amongst the main dimensions to discrete different cultures from a psychologist point of view. Such a contrast also becomes the main distinction in the East-West dichotomy. In this chapter, I will first conceptualise individualism and collectivism. The social behavioural differences resulting from these two core cultural values will be discussed. In the second and the third part of this chapter, I will discuss how people develop distinctive perspectives in regard to themselves and others under the impact of individualism or collectivism.

As explained previously, culture is a complex and amorphous concept. It has been studied in many domains including sociology, anthropology, humanities, linguistics, psychology and other social sciences. Researchers from various areas take different approaches to investigate culture, and focus on different aspects of culture. Psychologists consider the dichotomy between individualism and collectivism as a major factor according to which cultures can be broadly categorised (Triandis 1996). Such a dichotomy has been referred to as the "deep structure" of cultural differences (Greenfield 2000). A large body of behavioural research has shown that such cultural values influence individual-level psychological mechanisms. More recently, cognitive and neuroscientists alike have begun to investigate the neural substrate of these cultural differences, focusing on whether this diversity is powerful enough to modulate neural activity. In this chapter, I will begin by defining individualism and collectivism, to then focus on how these cultural values shape the way we understand ourselves and others. Importantly, data on the modulatory influences of cultural values and beliefs upon neural activity will be discussed.

1.2.1 Individualism and Collectivism

To identify one's culture upon encounter might be difficult. However, if one spends a few minutes to consider how one interacts with others, one might be able to make an accurate judgment. Indeed, the core of cultural differences lies in social activities (Hall and Hall 1990). People's exposure to all kinds of information in social interaction and culture shapes how their cognitive system perceives and makes use of it. Imagine a social scenario where a person brings some laughter to other people in the conversation. If he's from a Western culture, such as Europe or North America, he might consider himself to be a funny person. Instead, if he's from East Asia, he might likely thinks: "my friends think I am funny" or "in this circumstance I can be funny" (Trafimow et al. 1991; Triandis et al. 1990). Summarising similar observations, researchers have defined individualism and collectivism as follows:

Individualism: The core idea of individualism is that individuals are independent of one another (Bellah et al. 1985; Hsu 1983; Kagitcibasi 1994; Kim and Choi 1994; Markus and Kitayama 1991; Sampson 1977; Triandis 1995). Individualism centers on personal goals, personal uniqueness, and personal control. For instance, Hofstede (1984) defined individualism as "a focus on rights above duties, a concern for oneself and immediate family, an emphasis on personal autonomy and self-fulfilment, and the basing of one's identity on one's personal accomplishments". In individualistic societies people are autonomous: they give priority to their personal goals and behave primarily on the basis of their own attitudes rather than the norms of the general public (Triandis and Suh 2002).

Collectivism: The core idea of collectivism is mutual obligation and the common values shared among a society's members. In collectivism, one individual is merely a component of the social, a unit that subordinates to the larger context (Kagitcibasi 1987, 1997; Oyserman 1993; Schwartz 1990; Triandis 1995). In collectivistic cultures people are closely connected with their in-groups (family, tribe, nation, etc.). They give priority to the common goals of the majority. They usually behave within social norms, and are notably concerned with relationships (Mills and Clark 1982).

Early work by anthropologists and social psychologists had revealed many behavioural differences between individualism and collectivism. These differences exist in almost every aspect of an individual's social life including self-concept, well-being, attribution style, and relationship with others (Oyserman et al. 2002). Here I will outline some examples of these differences:

Motivation: In an individualistic society, people pursue personal uniqueness and desire to control their own lives, whereas in collectivistic cultures, people prefer to be like everyone else and follow orders (Kim and Markus 1999). As a result, personal choice generally enhances motivation more for individualism than collectivism. For example, Iyengar & Lepper (1999) showed that children from European-American backgrounds were more motivated when they were given a personal choice, and less motivated when the experimenter or peers made the choice for them. On the other hand, Asian-American children showed less motivation when they could choose for themselves. However, if their mothers or in-group member made the choices for them, Asian-American children showed the highest level of intrinsic motivation and performed the best.

Evidence also suggests that motivation in individualist cultures increases following success, but in collectivistic cultures it increases following failure. For example, Heine et al. (1998) showed that experiencing success motivated European Canadian undergraduates more than those from Japan. After experiencing failure, individuals from a collectivistic culture might be motivate to change themselves to better satisfy the demands from their social environment.

The presence of others also motivates individualism and collectivism in different ways. For example, Asians are motivated to justify their choice when significant others are primed (Kitayama et al. 2004). In another example, participants were exposed to a set of schematic faces that appear to be "watching" them from their perspective (Imada and Kitayama 2010). East Asians justified their choice when an impression of "social eyes" was primed during the choice. European Americans appear to show a weaker motivation effect under such conditions, reportedly because the eyes of others are experienced as unnecessary impositions on their freedom (Imada and Kitayama 2010).

Emotion, experiences and expressions: Depending on their cultural background, people experience emotion from different aspects. In individualistic cultures, emotions are self-focused. They reflect the status of personal feeling. In collectivistic cultures, emotions tend to be set in relationships and represent the status of these relationships (Mesquita 2001). Kitayama et al. (2000) showed that Americans reported more personal emotions (e.g., feeling superior, proud, top of the world), whereas Japanese reported more interpersonally engaged emotions (e.g., friendly feelings, feeling close, respect).

Early observations from anthropology and psychology also suggested different "display rules" of emotion for people from different cultures (Ekman and Friesen 1975; Matsumoto et al. 2008). While the individualists tend to express their emotions more freely, the collectivists usually restrain their emotional expression instead of being open and directly showing personal feelings (Niedenthal et al. 2006). Individualism is more expressive than collectivism, particularly for positive emotion, but also for negative emotion (Matsumoto et al. 2008). For example, the expression of anger is less prevalent in collectivistic than individualistic cultures (Markus and Kitayama 1991). However, most of these results are from observational studies or verbal self-reports. Cross-cultural research in emotions has not yet provided a clear link between the individualism/collectivism contrast and emotional expression (Oyserman et al. 2002).

In addition facial emotion recognition usually was considered as universal in the early literatures (Ekman et al. 1969). Recent evident suggested that observers from different cultures also perceive emotional face differently (e.g., Jack et al. 2012a; Jack et al. 2012b). Details will follow in the next chapter.

Communication: While people in individualistic cultures tend to speak openly, people in collectivistic cultures use indirect and sometimes ambiguous communication (Holtgraves 1997). Gudykunst et al. (1996) quantified communication styles and measured the level of individualism-collectivism among U.S., Australian, Japanese, and Korean students. They showed that indirect communication correlated negatively with individualistic cultures, and positively with collectivistic. In another study, among Korean, Japanese, and U.S. students, individualism was found to focus on clear, goal-oriented communication. Instead, collectivism was concerned about the listener's feelings, and desired to avoid negative evaluation (Kim et al. 1996).

Social behaviour: Members of a collectivistic culture are strongly influenced by the behaviour and thoughts of other people. For instance, Cialdini et al. (1999) examined how people respond to a request to participate in a market survey. They found that people from collectivist cultures were easily influenced by social proof arguments (e.g., your friend has complied with this request). People from individualist cultures, however, were influenced more by personal commitment arguments (e.g., you have complied with a similar request in the past).

Cultural values also change the way people handle social conflicts. Peng and Nisbett (Peng and Nisbett 1999) asked Chinese and American students to analyse contradictions drawn from everyday life. For example, one of the cases they presented to the students was a daily life conflict between mothers and their daughters on the daughters' time management of study and entertainment. American students tended to respond in favour of one side or the other (e.g. "mothers should respect their daughters' independence"). Chinese responses were more likely to find a "Middle Way" (e.g. "both the mothers and the daughters have failed to understand each other"). They found virtue and fault on both sides, and attempted to reconcile the contradiction.

In an individualistic society, people are encouraged to be independent, self-elevating, and assertive. Thus, one's dominant behaviour is usually positively reinforced (Moskowitz et al. 1994). In contrast, a collectivistic society tends to positively reinforce subordination, sociability, and cooperation (Triandis and Gelfand 1998). Freeman et al. (2009) observed opposite neural activity patterns in two cultural groups relating to dominant behaviour. American and Japanese participants passively viewed images of individuals posing dominance and submission during an event-related design functional magnetic resonance imaging (fMRI) scan. After the scanning session, the participants completed a survey to measure their personal endorsement of dominant versus submissive values (e.g., "I impose my will on others" and "I let others make the decisions") (Goldberg et al. 2006). Results of the survey corroborated previous studies showing that Americans tend to endorse dominant values and behave in dominant ways, whereas Japanese tend to endorse submissive values and express more subordinate behaviour. More importantly, they found a direct relation between participants' behavioural responses and their neural pattern. The neural activity in the bilateral caudate nucleus and medial prefrontal cortex (mPFC) showed opposite patterns in the two cultural groups. Identified as part of the mesolimbic reward circuitry, these two brain regions have been directly linked to reinforcements and rewards (e.g., Aharon et al. 2001; Breiter et al. 2001). Americans showed greater activity in these brain regions when perceiving dominant stimuli than subordinate stimuli, whereas the reverse pattern of neural activity in the same brain regions was shown among Japanese. These findings suggest that functional activity in the mesolimbic reward system is modulated in different ways, in order to coordinate with cultural preferences for dominant or subordinate behaviour.

Personality: Personality is the result of a combination effect from genetic and environmental factors (Engler 2008; Kellerman 2012). Among the most important of the latter are cultural influences. However, only a small number of studies have directly investigated the relationship between personality traits and individualism/collectivism. While studies showed consistent mean personality difference across different nations (Allik 2005; Terracciano et al. 2005), few studies have directly correlated personality with the cultural syndrome of individualism-collectivism (e.g., Hui and Villareal 1989). Further study is still needed to clarify this subject.

1.2.2 "Know Thyself": Self-construal and the Correlated Neural Activity

Culture modulates how we behave in social situations and interact with other in-groups. These modulations are internalized and further shape the way we think of ourselves (Triandis 1995; Zhu and Han 2008). Markus & Kitayama (1991) analysed how people from different cultures think about themselves in relation to others and suggested different self-construals between individualism and collectivism. Specifically, self-construal focuses on interdependence-independence, which is one of the most important aspects of the cultural syndrome of individualism-collectivism.

According to Markus and Kitayama (1991), the independent construal of the self is autonomous and independent. It attends to the self and self-focused information. On the other hand, the interdependent construal of the self emphasizes social connection and relationship. It is generally sensitive to information relating to others, and attends to intimate others as much as to the self.

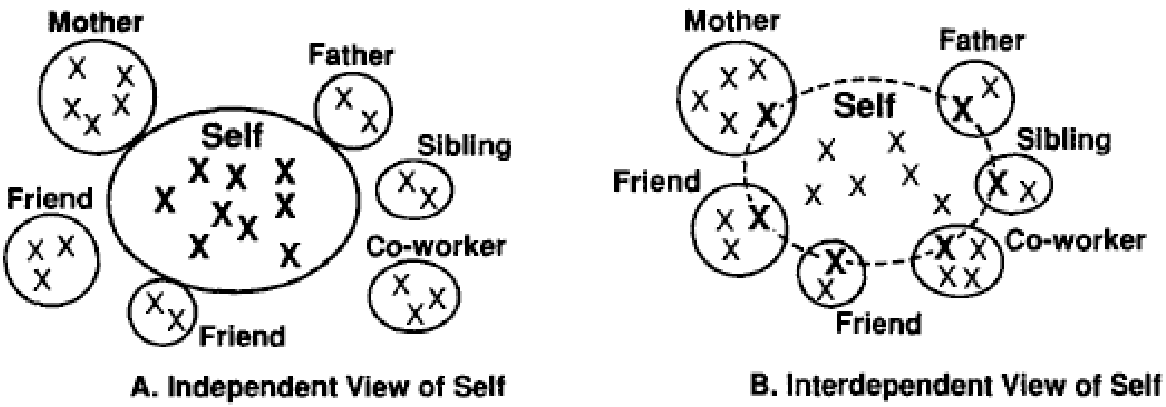

Figure 1.2.1, Conceptual representation of the self. A: Independent construal; B: Interdependent construal. Adapted from Markus and Kitayama (1991) with permission.

The differences between independent and interdependent self-construal are illustrated in Figure 1.2.1. The self is represented by the large circle, whereas smaller circles represent specific others. Within each circle are the various dimensions of the self or the others (mark as X). If two circles intersect, it means they share one or more similar aspects (the X in the intersection). As shown in Figure 1.2.1A, those with independent construal of the self do not share any inner attributes with others. They refer to their internal attributes such as their own traits, abilities, values, and preferences in self-definition. For those with interdependent self-construal, self-knowledge is generally based on their share elements with others who are close to them (Figure 1.2.1B). Thus, they define themselves mostly by relating to others.

Self-concept develops in an early stage of individual development. Starting from birth, mothers with different cultural backgrounds talk to their children differently. For example, Western mothers are more likely to focus on experiences and attributes about past events than Asian mothers (Leichtman et al. 2003). As a result of parenting and other environmental influences, the distinction between independent and interdependent selves shows at an early age in children. Hayward (2004) compared 5- and 6-year-old children from America and Japan and found that Japanese children scored higher on Collective Identity, Harm-Avoidance, and Social Closeness than American children in the Eder Self-View Questionnaire (Eder 1990). A similar study tested on preschool participants from Korea and the United States also confirmed that Korean culture fosters a relatively interdependent conception of the self (Ahn and Miller 2012).

Many self-related psychological processes are altered by our self-construal (Markus and Kitayama 2003). For example, previous results showed differences in self-related memory between independent and interdependent self. People from individualistic cultures usually hold better memory of information about the self than that about others. This is known as the self-reference effect (Klein et al. 1989). However, for the interdependent self, the advantage of self-related memory is much less significant (Conway et al. 2005; Markus and Kitayama 1991; Markus and Kitayama 2003). Westerners showed self-reference effect over close others such as mother and best friends in a trait memory task (Heatherton et al. 2006; Klein et al. 1989), whereas Chinese participants remembered equally well trait adjectives associated with the self and close others (Zhu and Zhang 2002). In another example, Wang and Conway (2004) studied cross-cultural differences in autobiographical memory. They found that European-American adults frequently focused on memories of personal experiences. Thus, people with independent self-construal place a great emphasis on their feelings and personal roles in memory events. In contrast, Chinese participants tended to describe memories of social and historical events. They focused more on social interactions and the roles of other people than the European-American participants. The result in autobiographical memories lends further support to the difference in memory related to independent-interdependent self-construal.

Moreover, the differences in self-representation are also reflected at a neural level. A series of recent studies on self-related tasks have shown different patterns of neural activation between people from individualistic and collectivistic cultures (Amodio and Frith 2006; Ames and Fiske 2010; Chiao et al. 2009, 2010; Zhu et al. 2007). Zhu et al. (2007) scanned two cultural groups (i.e., Westerners and Chinese) while they performed trait judgment tasks regarding themselves or a close other (i.e., their mother). Researchers contrasted trait judgments of the self and trait judgments of a public person to obtain a region of interest (ROI) related to the self, namely the medial prefrontal cortex (mPFC) and the anterior cingulate cortex (ACC). Previous studies showed that activation of mPFC would increase during the self-related task (e.g., Amodio and Frith 2006; Gusnard et al. 2001). Zhu et al. (2007) found that, for Chinese subjects trait judgments of themselves and their mothers both activated the mPFC compared to the trait judgment of a public person. In contrast, Western subjects' mPFC activation only increased during self-trait judgment, but not for mother-judgment or other-judgment. These findings provided the first neuroimaging evidence for cultural difference in self-related neural activity.

In another example, Chiao et al. (2009) scanned Caucasian Americans and Japanese while they made judgments of general trait descriptions or contextual self-descriptions. Moreover, they controlled each participant's degree of endorsement of independent and interdependent self-construals using the Self-Construal Scale (Singelis 1994). They found that people with individualist tendencies showed greater mPFC response while thinking of themselves in a general manner, whereas people with collectivist tendencies showed greater mPFC response while thinking of themselves in a relational manner. These results provided further evidence for the influence of cultural values on individuals' neural substrates underlying self-reflective thinking.

Some studies used face stimuli to investigate the differences in self-processing between Western Caucasians and East Asians. It has been proposed that self-face recognition (e.g., to recognise oneself in a mirror) is an indicator of high-level self-awareness (Keenan et al. 2000). Some authors hypothesised that people with independent self-contrual might assign more positive associations with their own face than to others' faces (Han 2013; Han and Northoff 2009). As a result, people with an individualist background might attend more to their own faces when presented amongst others' faces, and process their own faces more deeply (Sui and Han 2007; Sui et al. 2009). In contrast, as the East Asian emphasises social connections between the self and others, enhanced processing of one's own face may not be as strong compared to Westerners. For example, Sui & Han (2007) scanned Chinese subjects only while they performed an implicit face recognition task that required judgments of orientations of one' own face or a familiar face. Moreover, subjects were primed before the face recognition task with either independent or interdependent construals (Gardner et al. 1999) by marking independent (e.g., I, mine) or interdependent (e.g., we, ours) pronouns in an essay. They found that neural activity in the right middle frontal cortex increased when recognising their face, rather than familiar faces. Moreover, the right frontal activity differentiating between the self and familiar faces was enlarged by independent relative to interdependent self-construal priming. Increased right frontal activity was also associated with faster responses to their own face rather than familiar faces.

Furthermore, the same research group recorded event-related potentials from British and Chinese subjects while they judged head orientations of their own face or a familiar face (Sui et al. 2009). They observed faster responses to one's own face relative to the familiar face in both cultural groups. However, the self-advantage in behavioural performances was greater for British than for Chinese subjects. In addition, they found that one's own face elicited a larger negative activity at 280–340 ms over the frontal–central area (N2) relative to the familiar face in the British. In contrast, the Chinese showed reduced anterior N2 amplitude to their own face compared with the familiar face. Some evidence showed that frontal-central N2 component is sensitive to perceptual salience of stimuli (Folstein and Van Petten 2008). This is possibly associated with individuation and deeper processing of the face (Ito and Urland 2003; Kubota and Ito 2007). Thus, the authors suggested that the reverse pattern of the N2 in the cultural groups showed that independent self-construal endows their own face compared to familiar faces, and vice versa for interdependent self-construal. For people with interdependent self-construal, the properties of others contribute to a large portion of the self.

Brain mechanisms underlying self-investment in personal versus public choice have also been investigated. Park et al. (2012) tested a negative neural electric peak that occurs when an error is committed in a cognitive task (called error-related negativity or ERN). Evidence indicates that ERN increases as a function of motivational significance of the errors (Hajcak et al. 2005). In Park et al's (2012) experiment, immediately before each trial, participants were briefly exposed to a face prime (which is designed to induce an impression of being seen by others - the face-priming trials) or a control prime (the control trials). As predicted, Asians showed a greater ERN in the face-priming trials than in the control trials, but European Americans showed a reversed pattern, with a weaker ERN in the face-priming trials than in the control trials. Most importantly, the ERN magnitude in the witnessing-eyes priming condition was significantly correlated with self-reported levels of interdependence (versus independence) as assessed by the Singelis (1994) self-construal scale. In fact, the cultural difference in ERN in this condition was completely mediated by interdependent (versus independent) self-construal.

In summary, culture affects our internal self-related processing. People from individualistic cultures tend to develop an independent view of the self. In comparison, people sharing a collectivistic background tend to represent their self in an interdependent way. Different views of the self modulate how people process self-related information. Moreover, results illustrate that self-related neural activities are shaped by the construal of the self.

1.2.3 Understand Others: Theory of Mind and Empathy

As social animals, human beings are adapted to understand each other in order to communicate and share information. We are capable of attributing others' mental states (e.g., intentions, desires and beliefs) in order to interpret and predict their behaviour. This is one of the fundamental social abilities, and is referred to as "theory of mind" (ToM) or "mentalising" (Premack and Woodruff 1978; Wellman et al. 2001; Wimmer and Perner 1983). However, culture influences the way we interpolate others' behaviour and emotion (Han and Northoff 2008; Nisbett and Miyamoto 2005). For example studies showed that Americans were inclined to explain murders and sports events respectively by invoking presumed traits, abilities, or other characteristics of the individual, whereas Chinese and Hong Kong citizens are more likely to explain the same events with reference to contextual factors, including historical ones (Lee et al. 1996; Morris and Peng 1994). In this section, I will discuss the differences between individualism and collectivism in understanding others.

The first important aspect of the ToM is how people make sense of others' actions. This question has been investigated for nearly fifty years, and one of the fundamental discoveries is that people tend to explain others' behaviour as arising from their internal factors (their characters or personality), while neglecting situational causality (Gilbert and Malone 1995; Jones and Harris 1967; Ross 1977). This has been referred to as the "correspondence bias" or "fundamental attribution error". However, most of the early attribution studies were based on observations of the Western Caucasian population. As discussed previously, people in this population share a similar independent self-construal. While they refer themselves more to internal elements, they might also rely more on internal factors to define other people. Instead, people from a collectivistic culture pay more attention to situational forces in explaining the causes of people's actions (Nisbett 2003). As a result they might show less bias of this attribution error.

Indeed, evidences suggested that this allegedly universal bias might be much more pronounced for Western Caucasians than for East Asians (Choi and Nisbett 1998; Morris and Peng 1994). Many studies indicate that Asians are inclined to explain other person's behaviour by regarding to the situational factors (Lee et al. 1996; Miller 1984; Morris and Peng 1994; Norenzayan et al. 2002). Such cultural attribution differences persist even when situational factors are extremely salient (Jones and Harris 1967). For example, situation salience manipulations bias East Asians' attributions much larger toward external factors, whereas Americans may still attribute behaviour to internal factors such as personality traits (Choi and Nisbett 1998; Masuda and Kitayama 2004). In addition, East Asians are more likely to believe that behaviour does not correspond to actual attitudes than Westerners (Kashima et al. 1992). These findings suggest that East Asians' views about the causes of behaviour and the importance of situational factors differ from those of Westerners.

Interestingly, these differences in attribution bias were not only limited in explaining real world scenarios and social behaviour. Studies showed that individualists and collectivists gave different explanations even for events involving animals and inanimate objects. For example, Morris and Peng (1994) showed participants animations of an individual fish moving in relation to a group of fish in various ways. Compared with the Chinese, American participants were more likely to see the behaviour of the individual fish as being produced by internal factors of that fish. However, as for Chinese participants, they were more inclined to see the behaviour of the individual fish as being produced by external factors, namely the other fish. Another study asked Chinese and American participants with no formal physics education to explain some ambiguous physical events (phenomena involving hydrodynamics, magnetism etc.). They found that Americans referred more to dispositional factors (e.g., weight) and less to contextual factors (e.g., a medium) than did Chinese (Peng and Knowles 2003).

Another aspect of the ToM is to understand that others' mental representation of the situation can be different from your own. One of the classical tasks to quantify this ability is the false-belief task (Wimmer and Perner 1983). In this task the participant is usually observed or read a story in the third-person view, then answer several questions relating to the internal perspectives of the people in the story. The ability to accomplish the false-belief task is one of the landmarks of children's cognitive development. Studies on Western Caucasians found that, four-year-old children are generally able to succeed at false-belief tasks, whereas 3-year-old children tend to fail (Baron-Cohen et al. 2000). This pattern has been hypothesised to be universal, regardless of culture (Wellman 1998). However, recent evidence has suggested wide variations in developmental timing across cultures (Chen and Lin 1994; Naito 2003;

Vinden 1996). For example, the onset of false-belief understanding in Hong Kong children appeared much later (in some cases up to 2 years) than in Caucasian children (Liu et al. 2008). Moreover, even when they answer correctly, children from collectivistic cultures give different justifications compared to ones with an individualistic background. Naito & Koyama (2006) found that Japanese children usually referred to social rules rather than the internal or personal reasons commonly given by children from Western cultures (e.g., Bartsch and Wellman 1989; Wimmer and Mayringer 1998). These results suggest that children across cultures understand theory of mind in different ways. While children from individualistic cultures mentalise others' behaviour as personal and intentional, the ones from collectivistic cultures attribute them to the situation and surroundings. As a result, children from collectivistic cultures might struggle more to understand that other people can interpret the circumstances differently than themselves.

Recently, studies using fMRI showed that cultural differences in Theory of Mind can further affect our neural activities. For example, Kobayashi et al. (2006, 2007) scanned participants from Japan and America while they were performing adapted versions of false-belief task. In the brain regions associated with theory of mind (e.g., Brunet et al. 2000, 2003; Ferstl and von Cramon 2002; Fletcher et al. 1995; Goel et al. 1995), they found a comparable neural activity between subjects from individualistic and collectivistic cultures in the medial prefrontal cortex (mPFC) and anterior cingulate cortex (ACC). However, another crucial brain region related to the ToM task, namely temporo-parietal junction (TPJ), showed a different activity in Japanese participants than those from individualistic cultures. They found that the TPJ activation was much lower in Japanese children and adults (Kobayashi et al. 2006, 2007). It has been shown that the TPJ is involved in distinguishing self-agency from other agencies (Blakemore and Frith 2003; Decety and Grèzes 2006; Decety and Lamm 2007; Jackson et al. 2006). For individualistic cultures that have a more self-other distinction of theory of mind, the TPJ might be more involved in the related processing (Kobayashi and Temple 2009). Therefore, the diminished activity in TPJ in Japanese children and adults might reflect a weakened sense of self-other distinction in Japanese culture (Han and Northoff 2008; Perner and Aichhorn 2008).

Han & Northoff (2008 & 2013) also proposed an alternative explanation of why judgments of mental states produced greater activation of TPJ in American than in

Japanese participants. The TPJ might have a role in integrating sensory modalities and limbic inputs (Moran et al. 1987). Moreover, Kobayashi et al. (2006) found: that 1) Americans showed greater activation in the right insula, which has been suggested to mediate the connection between the limbic system and frontal regions of the brain (Allman et al. 2005); 2) greater brain activity for the Japanese participants than the Americans in their right orbital frontal gyrus, which has been shown to be involved in emotional mentalising tasks (Moll et al. 2002). Therefore, Han & Northoff (2008 & 2013) have argued that attributing mental states to other people might require the integration of sensory modalities and limbic inputs more for people who grew up in an individualistic culture than for people who grew up in a collectivistic culture. In contrast, people from collectivistic cultures rely more on emotional mentalising. However, this interpretation contradicted the finding in the following study by Kobayashi et al. (2007). In the later study, Japanese children showed higher activation in the left anterior superior temporal sulcus and temporal pole than American children in a cartoon based ToM task. The temporal pole has been suggested to integrate sensory information and limbic inputs (Moran, Mufson, & Mesulam, 1987). The authors argued that Japanese children had to integrate sensory and limbic inputs more than American children to complete the task, which opposes the interpretation by Han & Northoff (2008 & 2013).

Another study using fMRI also reported both cultural consistency and diversity in the neural networks associated with performance in a Theory of Mind task. Adams et al. (2010) showed observers from America and Japan photographs of human face eye regions, and asked them to interpolate their corresponding mental states. This is known as the ‘‘Reading the Mind in the Eyes’’ test, a well-validated social-perceptual test of mental state reasoning and theory of mind (Baron-Cohen et al. 2001). In both groups of observers, greater bilateral posterior superior temporal sulci (pSTS) activation was shown in same-culture mental state decoding than in other-culture. They also found activation difference in right TPJ between the two cultural groups. Different from Kobayashi et al. (2007), they found overall stronger activity during the experiment task in the right TPJ for subjects from a collectivistic culture (i.e. Japan) than those from an individualistic culture (i.e. America). Although the tasks applied in these two studies are different, it is too early to provide a definite explanation of these complex cultural differences in TPJ.

Interestingly, TPJ may also be modulated by cultural values in the empathy task (Cheon et al. 2011; de Greck et al. 2012). Using fMRI, Cheon et al. (2011) measured the neural responses of Korean and American participants while they gave an empathy level rating to scenes of racial in-group or out-group members in emotional pain. Compared to Caucasian-Americans, Korean participants showed stronger in-group biases in empathy behaviourally. Additionally, Koreans showed stronger neural responses within bilateral TPJ. Cheon et al. (2011) showed that larger in-group empathy bias was associated with larger neural response in these regions. However, for the empathy of anger, the TPJ activation shows an opposite pattern. One study found that Germans, compared to Chinese participants, showed stronger hemodynamic responses in the right TPJ to intentional empathy for anger than for baseline conditions (de Greck et al. 2012). These results suggest that the TPJ might have a general relationship with individualism-collectivism culture contrast, but how exactly it's modulated by culture values and the type of emotion still needs more investigation.

It is worth noting that in the same empathy study by de Greck et al. (2012), culture also modulates other brain regions. Participants from collectivistic cultures (i.e. China) showed stronger hemodynamic responses compared to those from individualistic culture (i.e. Germany) in the left dorsolateral prefrontal cortex (DLPFC). Previous studies have reported the involvement of the DLPFC in emotion regulation and inhibition (MacDonald et al. 2000; Ochsner and Gross 2005; Ochsner et al. 2004; Shackman et al. 2009; Vanderhasselt et al. 2006). The larger left DLPFC activation of Chinese participants might reflect a higher suppression of anger-related feeling in collectivistic cultures. The authors also claimed to observe regions that were directly related to the level of interdependency/independency. They showed a larger BOLD signal in the right inferior temporal gyrus, right superior temporal gyrus, and left middle insula for the contrast of empathy with anger minus baseline in Germans than in Chinese subjects. Hemodynamic responses in these three brain regions negatively correlated with interdependences scores over all subjects acquired after the fMRI scan. However, it might not be appropriate to combine the two cultural groups together in the correlation analysis as they did. The percentage of signal changes in these three regions actually positively correlated with interdependences scores for Chinese participants (see Figure 3 in de Greck et al., 2012; however the authors didn't report the statistic of the correlation independently for each group of observer). The relationship between these brain areas and the level of interdependency/independency thus remains unresolved.

Overall, there are cultural differences in BOLD activation during interpolation of mental or emotional states of others. Most of the current studies have shown cultural diversity in the temporo-parietal junction (TPJ). However, the results among studies are inconsistent. Further examination is required to help identify the underlying social psychological differences between individualist and collectivist observers.

1.3 Culture Shapes Human Perception and Cognition

Preamble

The effects of culture are not limited to social behaviour and other forms of high-level cognition. Under the theoretical framework of analytic vs. holistic cognitive styles, cultural differences in low level perception and cognition were supported by various behavioural and neuro-cognitive studies. However, such cognitive style frameworks can be restricted, given the current results on face perception. In this chapter, cultural differences in perception and cognition will be reviewed according to the stimuli and tasks applied in different studies. Interpretations are made under cognitive style theory and the information-tuning hypothesis.

Individuals from different cultures hold diverse values and beliefs. As discussed in the previous chapter, a body of research has led to a generalisation of two distinct cores of cultural values: individualism and collectivism. Furthermore, the cultural values we hold affect how we think of ourselves and interpret others' behaviour, and modulate the related neural activity. Similar investigation of how social environmental factors impact upon brain functioning has provided researchers with a new perspective, that high-level cognition and its neural architectures are not universal. In contrast, low-level perception and cognition and their neural substrates have been considered to be culturally independent. However, recent behavioural and neuroimaging data has fundamentally questioned these assumptions, highlighting the diversity of perceptual and cognitive processes across different cultures.

Indeed, behavioural and brain imaging results showed differences between individuals from Western and East Asian cultures on various cognitive domains. Mainly focused on visual perception, differences were found in: attention (Chua et al. 2005; Hedden et al. 2008; Ji et al. 2000), perception (Blais et al. 2008; Lynch et al. 1990; Lynch et al. 1991; Neuhaus 2003), categorization (Choi et al. 1997; Norenzayan et al. 2002), memory (Masuda and Nisbett 2001), logical reasoning (Norenzayan et al. 2002), change prediction (Ji et al. 2001), and tolerance of contradiction (Peng and Nisbett 1999).

Early theoretical frameworks introduced by Nisbett et al. (2001) suggested two different cognitive styles that directly link to the two distinct cultural values. People from individualistic cultures, such as those in America and Europe, develop an analytic processing bias. They tend to emphasise focal objects and thinking in a context-independent style. In contrast, in collectivistic cultures such as Japan, China, and Korea, people tend to broadly divide their attention to contextual or background features. They adapt a holistic reasoning style that focuses on the connections among objects or the relationship between an object and its context (Markus and Kitayama 1991; Nisbett et al. 2001; Triandis 1995). Importantly, different cognitive styles modulate the information we attend to, and further bias the way we perceive and make use of this information.

However, in the original work by Nisbett, as well as the follow up studies that investigated the contrast between analytic and holistic processing styles, the type of information being processed by different cultural observers was never actually quantified. Crucially, recent evidence on face perception has shown that, even though Western Caucasians (WCs) and East Asians (EAs) applied different eye movement strategies to face stimuli (face features), the information being perceived was actually the same (Caldara et al. 2010). It's debatable whether the perceptual and cognitive differences between individualism and collectivism should be described in terms of two distinctive cognitive styles, or as biases in perceptual/information gathering strategy.

In the following chapter, I will elaborate on the cultural differences in perception and cognition according to the stimuli and tasks which have been employed in vision studies. Some of these studies were originally conducted under the hypothesis of the analytic-holistic cognitive style. However I will discuss them under a broader framework, focusing on how our perception system is culturally tuned to different information.

1.3.1 Object and Scene

Nisbett et al. (2003; 2005; 2001) suggested that one of the main differences between analytic and holistic processing style lies in the way people attend to objects and their surroundings (either other objects or the environment in general). Several behavioural studies have suggested that WCs focus on the focal object and its property within a scene, whereas EAs attend to the background/context or relationship between objects (Kitayama et al. 2003). Such cultural variation in visual perception is believed to occur because of the internalization of social information preferences (i.e., the emphasis of internal factor in individualistic culture and the emphasis of relationship in collectivistic culture; Gutchess et al. 2010; Kitayama et al. 2003).

Early studies in developmental psychology observed differences in parenting that might contribute to the formation of cultural perceptual differences. For example, when American mothers play with their children, they tend to direct the children's attention to objects and their properties (“see the truck; it has nice wheels”), whereas Japanese mothers emphasise feelings and relationships (“when you throw your truck, the wall says, ‘ouch’”). Moreover, American mothers label toys and point out their attributes more often than Japanese mothers do (Bornstein et al. 1990a; Bornstein et al. 1990b; Fernald and Morikawa 1993). By contrast, Japanese mothers tend to engage their infants in social routines more than American mothers. Thus, the perceptual differences observed in adults between different cultures might originate from the early experiences of the everyday environment.

A number of attempts have been made to assess attentional differences between Western Caucasian and East Asian in object and/or scene perception. For example, in an early study Masuda and Nisbett (2001) first showed short animated video clips of underwater scenes to Japanese and American participants, then recorded their verbal descriptions of the videos. American subjects tended to begin by describing the most salient object, whereas Japanese participants were more likely to first outline the context. Japanese subjects also reported more background details than Americans. The same objects from the clips were then presented to the participants in a separate session, but with one of the following backgrounds: the original, a new background, or no background at all. Results showed that background manipulation affected the performance of Japanese but not American participants. Similar results were shown when the experimenters presented previously seen real-world objects to the subjects. Japanese were less likely than Americans to correctly recognise the object if it was presented in a different context. Moreover, in later work, Masuda & Nisbett (2006) reported that EAs were more likely than WCs to detect changes in contextual information within a scene in a change blindness paradigm.

However, the bias towards object or background between WC and EA observers is not well supported by eye movement evidence. Some studies showed a cultural difference in fixation number and fixation duration between WCs and EAs while they were viewing scene stimuli with objects inside (Chua et al. 2005; Goh et al. 2009; Masuda et al. 2008a). Chua et al. (2005) showed that Americans spent a greater proportion of viewing time on objects relative to backgrounds than Chinese participants. Although the fixations that landed on objects generally lasted longer than those which landed on the background, the contrast between the two was larger for American participants than for Chinese participants. (However, as shown in Chua, Boland, & Nisbett, 2005 figure 3c, the overall fixation duration of American participants was longer than the Chinese. They should have compared the relative contrast instead of the absolute contrast). In addition, while the number of object fixations was similar in both groups, the Chinese made more background fixations than Americans. A similar result by Goh et al. (2009) also found that Americans mainly fixated on the foreground object in a picture, whereas East Asians shift their gaze between the foreground object and the background constantly. However, other studies report little or no difference between the two cultures (Evans et al. 2009; Miellet et al. 2010; Rayner et al. 2009; Rayner et al. 2007). For example, a direct replication of Chua et al. (2005) did not find any difference between the two cultural groups (Evans et al., 2009). In another study, experimenters showed participants scenes consisting of several identifiable objects. They found no differences between Westerners' and East Asians' eye movements (Rayner et al., 2007). Similarly, Rayner et al. (2009) showed Americans and Chinese the same photographic scenes, containing either a usual or highly unusual object. Even though there were differences between the scan path deployed to explore normal and unusual versions of the scenes, no cultural difference was found. They reported that eye movements were quickly drawn to highly unusual aspects of a scene in a similar way in both groups of observers. Recently, Millet et al. (2010) applied a gaze-contingent technique to dynamically mask central vision (i.e. Blindspot) during a visual search task of animals in natural scenes. Both groups of observers showed comparable animal identification performance, which decreased as a function of the Blindspot sizes (0°, 2°, 5°, or 8°). Dynamic analysis of the exploration pathways revealed identical oculomotor strategies for both groups of observers during animal search in scenes. The result showed that culture does not impact on extrafoveal information use during a visual search. It is worth noting that the coupling between fixated and processed information is not perfect (concepts of overt vs. covert attention, see Posner 1980). WC and EA observers might use the same eye movement strategies, but extract different information from the environment, or vice versa (see Blais et al. 2008; Kelly et al. 2010; Kita et al. 2010; Rodger et al. 2010 in the case of face stimuli). Thus, the cultural modulations of eye movement in object and scene perception still remain unresolved.

Despite the inconclusive results in eye movement, fMRI studies showed that the attentional bias towards objects for individualism affect neural activity within the visual cortex. For example, Gutchess et al (2006) showed American and East Asian participants pictures of an object alone, scenes without an object or an object within a meaningful scene. Overall they found that Americans showed greater activation in object-processing regions than East Asians. The activation differences were shown in the ventral visual cortex, as well as in areas associated with semantic processing of objects (i.e. bilateral middle temporal, right superior temporal, and left superior parietal regions). However, they did not deploy any precise measurement to identify the brain area related to object or scene processing (i.e. a standard region of interest localizer of LOC or PPA). Instead, they created two masks by contrasting the object-only and scene-only trials, and compared the activation of subject viewing combined pictures (stimuli containing both object and background) within these two masks. Although the authors suggested that their approach increases sensitivity in detecting cultural differences, and has advantages over defining regions of interest a priori by using the whole brain as the initial search space, the appropriateness of such a method is arguable (Han and Northoff 2008).

In another study, Goh et al. (2007) employed a fMRI adaptation paradigm to evaluate how culture shapes the object-processing related brain area as a function of age. They presented images composed of objects and scenes with changes of object, scene, or both. Previous work demonstrated that attention modulates the adaptation effects in the ventral visual processing stream. Larger adaptation might indicate better functional integrity than weak or absent adaptation (Chee et al. 2006; Chee and Tan 2007; Eger et al. 2004; Murray and Wojciulik 2003; Yi and Chun 2005). Goh et al. (2007) thus hypothesised that due to prolonged exposure to an object-biased culture, elderly WCs would engage more during object-processing than elderly EAs, resulting in a larger adaptation effect in the correlated brain regions. In contrast, elderly EAs would show more adaptation effect in their background-processing areas than elderly WCs. Contradictory to this hypothesis, background processing was relatively similar across both age and culture. Specifically, the parahippocampal place area (PPA) showed nearly equivalent activation and adaptation magnitude across all conditions. However, the lateral occipital complex (LOC), indexed as an object-processing region (Grill-Spector et al. 2001; Grill-Spector et al. 1999; Grill-Spector et al. 1998), showed an Age x Culture interaction. The BOLD responses in bilateral LOC were generally less in older adults than younger adults. Moreover, the elderly WCs showed significantly larger object-processing adaptation than did elderly EAs, suggesting that neural sensitivity to object processing might decline with age disproportionately in EAs. However, they only observed Age x Culture interaction over the right LOC. Nonetheless, this finding demonstrates that the perceptual bias towards objects might accumulate through experience. More efficient object processing (represented by more adaptation effect within object–related regions) in individualism than collectivism becomes even more distinctive with age (Miyamoto et al. 2006; Nisbett and Masuda 2003; Nisbett et al. 2001).

In a subsequent study adapting a similar adaptation paradigm, Jenkins et al. (2010) investigated culture-modulated attention bias by presenting participants with incongruent scenes. The incongruent scenes were created by placing an object against a background where it would not commonly be found (e.g., a cow in a kitchen). Since observers from a collectivistic culture would attend to the relationship between an object and its background, an incongruent scene would attract their attention more than a congruent scene. For Chinese participants only, Jenkins et al. found that neural activity in the bilateral occipital cortex showed significantly larger adaptation to incongruent scenes than to congruent scenes. This indicates greater engagement with object processing in Chinese participants when the objects appear in incongruent contexts than when they appear in congruent contexts. The author suggested that, Chinese participants, sensitive to the context in which an object is embedded, pay more attention to that object when the context is semantically inconsistent. American participants, in contrast, are less likely to pay attention to an object that violates normal semantic relationships.

The attentional bias to incongruent information for collectivism observers has also been observed in one ERP study (Goto et al. 2010). Participants were presented first with a background picture (e.g., a car park). Then, a semantically congruent or incongruent object was shown superimposed upon the background (e.g., a car or a crab). They found that a negative ERP component peaking at about 400 ms after stimulus onset (N400) was affected by culture. For East Asian American observers, the N400 amplitude was larger when the target object was presented on a semantically incongruent background than a congruent background. Such amplitude difference was not shown by European or American participants. Moreover, they also found that higher N400 magnitude difference between conditions was associated with lower independent self-construal scores across all the subjects. It has been suggested that N400 amplitude is sensitive to semantic relationship processing (Kutas and Hillyard 1984). Asian Americans might be more prone to detecting the incongruity than Europeans or Americans due to their relative sensitivity to context. This result further supports the behavioural observation that collectivism is biased more towards the relationships between an object and its background.

The cultural attentional bias towards objects or relationships between objects further shape how we make use of this information. When they are asked to categorise different objects together, WC observers tend to classify them on the basis of rules and properties, whereas EAs tend to classify on the basis of similarity and relationships. For example, Chiu (1972) asked American and Chinese children to group two of three different items together (e.g., a man, a woman, and a baby). He found that American children were much more likely to group objects on a "categorical" basis than Chinese children. They put the man and the woman together "because they are both adults". In contrast, Chinese children were more "relational-contextual". They grouped together a woman and a baby "because the mother takes care of the baby". Similar results were shown in adult subjects across various tests (Gutchess et al. 2006; Ji et al. 2004; Unsworth et al. 2005). For example, Norenzayan et al. (2002) showed participants two groups of animated objects and asked them to classify the target object in one of the groups (see Figure 1.3.1 as an example). EAs were inclined to think that the object was more similar to the group with which it shared a family resemblance (i.e. to the group on the right in Figure 1.3.1), whereas Europeans and Americans were more likely to regard the object as similar to the group to which it could be assigned by application of the rule (i.e. to the group on the left in Figure 1.3.1 as they all have the same topmost string).

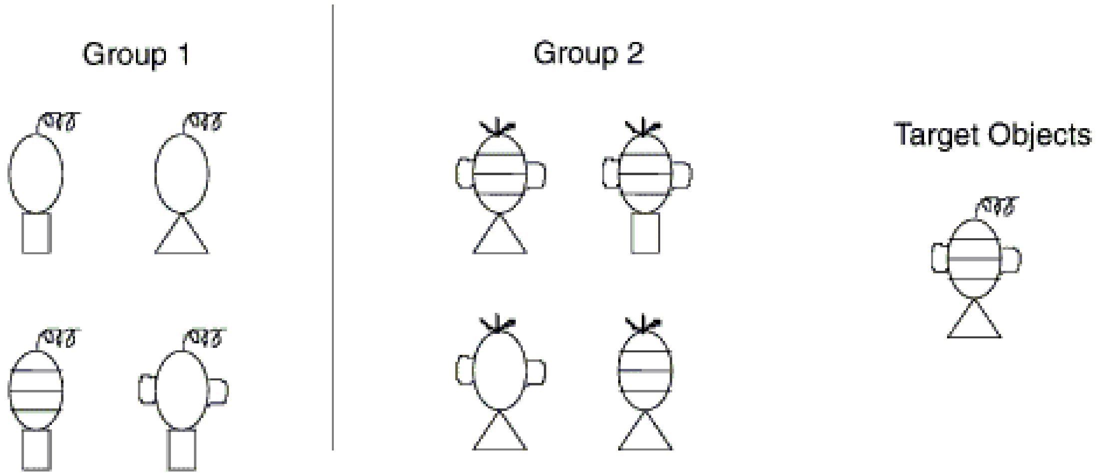

Figure 1.3.1, Examples of stimuli used in Norenzayan et al. (2002). The target object bears a strong family resemblance to the group of objects on the right, but there is a rule that allows placing the object in the group on the left (the style of the topmost string).

Studies using fMRI found differences in the brain activities related to the two categorical strategies at a semantic level. Gutchess et al. (2010) asked WC and EA participants to match two words out of three words either following the “category” rule or the “relationship” rule. For example, participants were presented with word triplets “panda-banana-monkey”. In the “category” condition, participants selected two words that belonged to the same category (e.g. panda and monkey). In the “relationship” condition, participants selected the two words that shared a functional relationship (e.g. monkey and banana). An extensive network including frontal, temporal and parietal regions were activated in both groups of observers in both tasks. Moreover, EA observers showed stronger activations in the right angular gyrus and the right middle frontal gyrus in both tasks than WCs. As comparison, the right cingulate gyrus is more activated in WCs compare to EAs in category tasks. The authors suggested that, EA observers engaged more top-down controlled processes to inhibit irrelevant information and select one strategy from the other. This resulted in stronger frontal-parietal network activation (Collette et al. 2005; Corbetta and Shulman 2002; Wager and Smith 2003). As for WC participants, they engaged more in solving the semantic conflict among word pairs rather than selecting an appropriate strategy. This activated the brain regions related to semantic information processing, such as temporal lobe regions and the cingulate gyrus (Copland et al. 2007; Lambon Ralph et al. 2009; Sass et al. 2009). Although Gutchess et al. (2010) did not find any special neural tuning direct link to a culturally preferred task (i.e. the category task for WCs and the relationship task for EAs), the results showed that culture affects participants' neural activation during categorisation.

Overall, the results from both behavioural and brain-imaging showed differences between individualism and collectivism in object/scene related processing. While WCs showed attentional and perceptual bias towards focal objects, EAs usually perceive more information from the background, the relationship among objects, and the connection between objects and background (Nisbett et al. 2001; Nisbett and Masuda 2003). These biases further affect our brain activities, sometimes possibly even leading to two completely different neural mechanisms processing related information. It also suggests the possibility of two diverse information-binding strategies for WCs and EAs. For observers from WC culture, they are better at decoding local information. In contrast, EA observers are better at global information processing (Nisbett et al. 2001; Nisbett and Masuda 2003).

1.3.2 Face and Emotional Face

The ability to recognise faces and facial emotions is a crucial skill for effective social interaction. The early literature suggested a systematic and universal eye movement strategy employed by adults to extract facial information. As revealed in the seminal work by Yarbus (1961), human beings make fixations to the eye and mouth regions while viewing faces; overt visual attention directs our eyes toward these desired visual locations. Since then, eye movement studies have consistently shown a similar triangular scan-path in face processing, with dominance given to the eyes (e.g., Althoff and Cohen 1999; Groner et al. 1984; Henderson et al. 2005). However, these previous findings were based on a sample of adults from WC cultures only. Thus, whether human beings deploy a universal eye movement strategy to encode and recognize faces remains uncertain.

To resolve this question, our lab (Blais et al. 2008) recorded the eye movement of both WC and EA observers while they were performing various face related tasks. Moreover, to properly estimate the differences in fixation patterns, we developed a data-driven eye-tracking data analysis method that does not require pre-defined regions of interest (i.e. *iMap*, see chapter 1.5.1 for details). Consistent with previous findings, we showed an eye-mouth fixation bias for WC observers. However, compared to WCs, EA participants directed their fixations more to the central area of the face (see Figure 1.3.2 first row). Both WC and EA subjects showed comparable behaviour performance. Divergent scan patterns deployed by different cultural observers were consistent across tasks (i.e. learning, recognition, and categorisation) and not affected by the race of the face being observed (i.e. Caucasian or Asian faces).

Follow up studies from our lab and other independent research groups around the world further confirmed the differential oculomotor patterns during face processing between individualistic and collectivistic cultural observers (Caldara et al. 2010; Kelly et al. 2010; Kita et al. 2010; Miellet et al. 2013; Rodger et al. 2010). Such fixational biases seem to arise as early as 7 years old in development (Kelly et al. 2011b) and persist for second-generation immigrants from an Eastern to a Western country (Kelly et al. 2011a). Interestingly, the same differences were observed for inverted faces (Rodger et al. 2010) and extended to visually homogeneous objects like animal faces or greebles (Kelly et al. 2010). See Figure 1.3.2 for a summary of the representative results.

During eye fixation, sharp central vision from the fovea centralis samples the maximum acuity of information for visual processing. Due to the fact that the eyes and mouth contain the most diagnostic information of the human face (Davies et al. 1977; Gosselin and Schyns 2001; Rowley et al. 1998; Viola and Jones 2004), it is puzzling how EA observers recognize faces by fixating on a redundant facial feature (i.e., the center of the face). To address this issue, Caldara et al. (2010) applied a gaze-contingent paradigm that limits the extra-foveal information. In this experiment, Gaussian apertures ("*Spotlights*") actively centred on participants' fixations while they were exploring a face. In the condition of 2° visual angle (foveal vision only) and 5° (extra-foveal vision largely limited), the *Spotlight* only covered a small area of facial features. For example, the eyes and the mouth were not visible when participants were fixating on the nose in these two conditions. However in 8° condition, both eyes and mouth were available when participants fixated on the nose. As a result, the center fixation strategy for EA observers disappeared in both the 2° and 5° conditions. Instead, they looked at the eyes and mouth in a similar manner to WC observers. In the 8° condition in which extra-foveal information was available, EA observers reverted to their preferred center fixation strategy. These results suggest that despite cultural variance in eye movements, WC and EA observers universally rely on similar facial information to recognise faces. Importantly, WCs preferentially sample foveally the diagnostic features in natural vision, whereas EA observers rely preferentially on extrafoveally extracted diagnostic features (eyes/mouth) sampled from central fixation locations (on the center of the face). However, both eye movement strategies can efficiently obtain information from facial features (i.e. eyes and mouth).

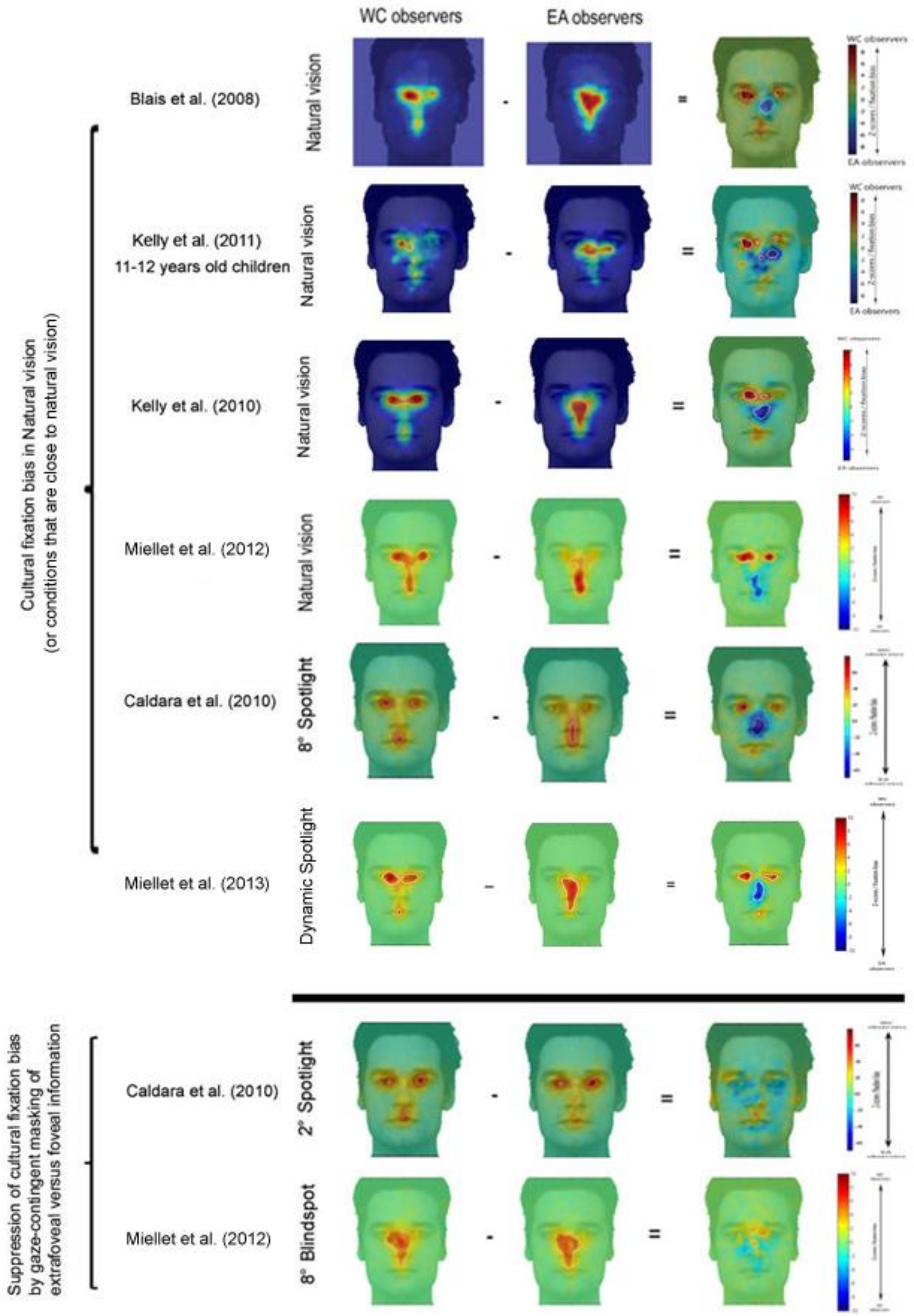

Figure 1.3.2, Upper panel: Fixation biases for WC and EA participants during natural vision or conditions equivalent to natural vision in previous studies. Lower panel: Spotlight (Caldara et al., 2010) and Blindspot's (Miellet et al., 2012) results revealing the abolition of the culture-preferred fixation strategy when the available visual information is restricted. Adapted from Miellet et al. (2012) with permission.

The results also showed that the culturally shaped eye movement pattern we deploy during face recognition is also highly flexible. Similar conclusions were reached with another gaze-contingent technique. Miellet et al. (2012) used a moving mask (i.e. *Blindspot*), which forced the participant to use extra-foveal visual information. The size of the mask was also parametrically manipulated (0° = natural vision, 2°, 5°, and 8° of visual angle). The results showed that the cultural fixational biases of faces were abolished by the size of the mask. In the larger *Blindspot* conditions, WC abandoned their usual triangular fixation strategy and shifted toward the typical EA central fixation pattern. Instead, EA observers were insensitive to the *Blindspot* manipulations.

To precisely quantify the foveal and extra-foveal information sampled from different cultural eye movement strategies, Miellet et al. (2013) developed another gaze-contingent technique similar to *Spotlight*. Instead of a fixed size Gaussian window, the *Spotlight* aperture expanded with time (1° every 25ms). Moreover, information outside of the *Spotlight* was replaced with an average face template to allow saccade programming without providing useful information for the experiment task. Therefore, participants would remain fixated on the same location until they obtained enough foveal and extra-foveal information for the task at hand. Consistent with the previous result, WCs fixated more on the eyes whereas EAs were significantly biased towards the center of the face. Importantly, Miellet et al. (2013) employed a retinal filter based on spatial frequencies decomposition, and reconstructed the visual information available in the stimulus according to the fixation pattern of each group of observers. The analysis showed that WC observers relied on local high-spatial-frequency information sampled from the eyes and mouth, whereas EAs used global low-spatial-frequency information from the same facial features (Figure 1.3.3).

Overall, these gaze-contingent studies (i.e. *Spotlight, Blindspot, Expanding Spotlight*) further supported the notion that people from collectivistic cultures developed different eye movement strategies compared to people from individualistic cultures. Human beings flexibly engage in *local* or *global* eye movement strategies and constantly adjust them in adapt to constrained visual situations (*Spotlight* & *Blindspot* result). Moreover, cultural-biased eye movement strategies extract information from the same facial features (*Spotlight* & *Blindspot* result). However, the spatially filtered information obtained from different strategies is culturally tuned (*Expanding Spotlight* result).

The information sampling and eye movement strategy differences among cultures also expand to categorization of facial expressions of emotions (e.g., Jack et al. 2009; Kelly et al. 2011a). The universality of facial expression has been questioned by various behavioural studies (e.g., Biehl et al. 1997; Ekman et al. 1987; Ekman et al. 1969; Matsumoto 1992; Matsumoto and Ekman 1989; Moriguchi et al. 2005). For example, Russell et al. (1993) reported that Japanese individuals often mistake fearful faces for surprised faces. Similarly, Jack et al. (2009) showed that EA observers preformed significantly worse in recognizing "fear" and "disgust". Moreover, using eye tracking and a model information sampler, Jack et al. (2009) showed that EA observers systematically biased their fixations towards the eye region and sampled information that is highly ambiguous for distinguishing between certain expressions (i.e., ''fear'' and ''surprise''; ''disgust'' and ''anger''). EA observers mainly involved the eye region but not the mouth as diagnostic for facial expression categorization. The internal representation of facial expressions might be different for EA and WC observers.

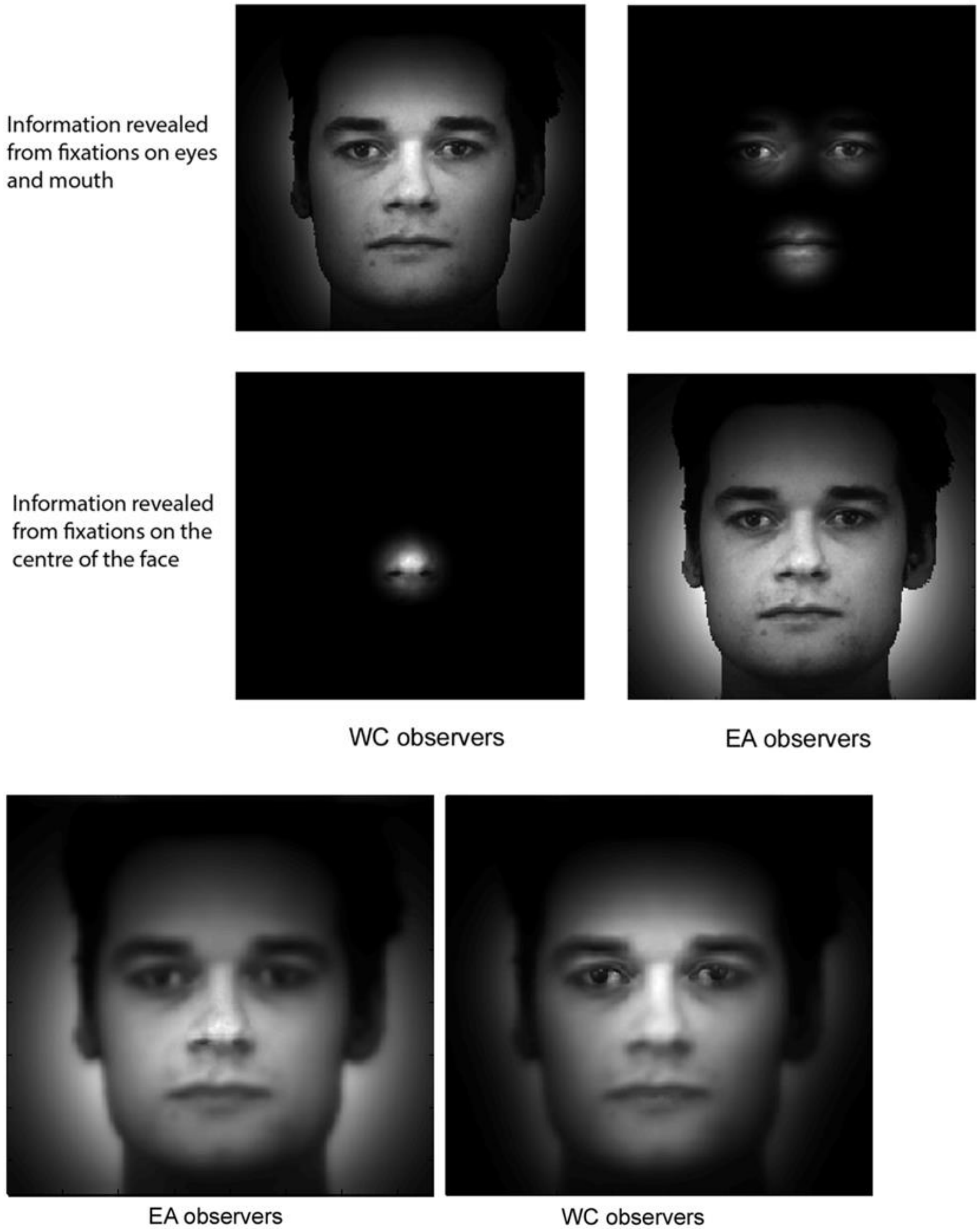

Figure 1.3.3, Upper panel: information reconstruction based on spatial-frequency decomposition. White area shows the available information on different facial fixation locations from the retinal filter. The size of the Gaussian aperture is determined by the expansion velocity of the Spotlight and the average fixation duration in the corresponding significant area. Lower pane: Information span for the global (EA) and local (WC) strategies. Adapted from Miellet et al. (2013) with permission.

Using reverse correlation, Jack et al. (2012a; 2012b) further estimate the cultural-specific internal representations of the basic facial expressions of emotion. For example, Jack et al. (2012a) presented neutral faces with white noise to WC and EA observers. Participants categorized the faces into one of the six basic facial expressions of emotion (i.e., happy, surprise, fear, disgust, anger and sad). According to their behavioural response, they averaged the noise templates to reconstruct the internal representation of each emotion expression. Indeed, the internal representations of facial expressions are very different between WC and EA observers. While the eyebrows and mouth were primarily featured in the WC representations, the EA representations of emotion expressions are mainly constructed only with the information from the eye region. Moreover, the result showed that the gaze direction is also an important feature of the EA internal facial expression templates. In a later study following the same logic, Jack et al. (2012b) presented participants computer generated three-dimensional facial animation of random facial movements and asked them to interpreted them into a meaningful facial expression. The facial movements were comprised by stimulation of random face muscle movements. Using dissimilarity matrices and cluster analysis, they showed that WC and EA rely on different facial movements to categorize emotion expressions. While WCs represent each of the six basic emotions with a distinct set of facial movements, the clusters of EAs' representation often overlap particularly for "surprise", "fear", "disgust", and "anger". Moreover, EA observers judged emotion intensity primarily according to the early muscle movements around the eyes, whereas WC judged emotional intensity with other parts of the face.

For observers from collectivist cultures, their facial expression perception is highly influenced by the social and environmental factors. For example, they tended to bias their categorization responses toward less socially threatening emotions (e.g., perceive "fear" as ''surprise''; see Jack et al. 2009; Moriguchi et al. 2005). Using cartoon face, Masuda et al. (2008b) showed that Japanese observers' perception of facial emotion was influenced by the surrounding faces, but not Westerners'. In another example, Goto et al. (2013) presented emotional faces superimposed on top of affective scenes in an ERP experiment. Asian Americans showed greater N400 response to incongruent trials (e.g., positive emotion face superimposed upon a negative scene) than to congruent trials, whereas no difference in amplitude across the two conditions is observed in European Americans.

Overall, culture biases the information we sample from face stimuli for identity recognition and emotion recognition. However, it is worth noting that face perception system is not solely sculpting by culture (Pascalis et al 2002; 2005). None the less, people from different cultures tend to rely on diverse spatial frequency information for face identification, and different spatial/temporal information for emotion expression task. These differences affect our eye movement strategy, behavioural performance and even our brain activities.

1.3.3 Non-cultural Stimuli and Other Cognitive Tasks

The cultural bias in perception and cognition even expands to low-level, culture-free abstract visual stimuli. One of the first evidences is demonstrated by Ji et al. (2000). They presented WCs and EAs with the rod-and-frame test (RFT), designed by Witkin and colleagues to assess the differences between field-independent and field-dependent (Witkin 1967; Witkin and Berry 1975; Witkin and Goodenough 1977). The concept of field dependence was developed by Witkin (1967) as an index of cognitive style. On one extreme (i.e., field-independent), observers tend to separate the target from the environment (i.e., field). Observers whom are in the other extreme, defined as field-dependent, incline to see the world as a whole. In the RFT task, a rod or line appears in a frame, which can be rotated independently from the rod. Participants were asked to judge when the rod appeared to be vertical but ignore the position of the frame. EA participants made more errors in this task than WC participants. The researchers interpreted it as a result of the difficulty to separate the rod from the whole field for EA observers (i.e., EAs are more field dependent).

Based on the RFT, Kitayama et al (2003) developed the Framed-Line Test (FLT). In this test, the stimulus was a vertical line within a square frame. After viewing the initial stimulus, participants were then shown a same or different size square frame and asked to draw a line within the frame. In the absolute task they were asked to draw a line the same length as the previous line; in the relative task the line being drawn was proportionate to the height of the surrounding frame. The results showed that observers from a collectivistic culture (i.e., Japan) performed better in the relative task, whereas those from an individualistic culture (i.e., America) were more accurate in the absolute task. However, Zhou et al. (2008) attempted to replicate the FLT in China and USA but without success. They showed that people estimated a line's relative length more accurately than its absolute length, regardless of culture.

Nonetheless, Hedden et al. (2008) deployed a modified FLT to test in two groups of observers and showed cultural differences in neural activities. Participants were presented with a series of stimuli, each consisting of a vertical line inside a box. The context-dependent task required judgments of whether the box and line combination of each stimulus matched the proportional scaling of the preceding combination. The context-independent judgment task required judgments of whether the current line matched the previous line, regardless of the size of the accompanying box. Hedden et al. (2008) found no difference in accuracy between the two tasks for either group of participants. However, the fMRI results showed an interaction of culture in the prefrontal and parietal cortices. Specifically, BOLD responses were higher in these areas during context-dependent than context-independent tasks for WCs, whereas EAs exhibited stronger activity in the same areas during the context-independent than context-dependent tasks. The opposite patterns of neural activity might reflects the enhanced sustained attentional control during culturally non-preferred tasks in comparison with preferred tasks (Hedden et al. 2008).

Stronger neural activation of the attention network during culturally non-preferred tasks was also evidenced in another fMRI study. Goh et al. (2013) asked participants to judge the related distances between a dot and a line during scanning sessions. This is a visuospatial judgment task involving relative contextual judgments, which are typically more challenging for Westerners. Behavioural results showed that WCs responses were slower than EAs. They also showed greater neural engagement compared to EAs in frontal, parietal, and occipital areas, as a result of the greater difficulty of the task. Moreover, WC observers also showed greater suppression of the default network, a brain network that is suppressed under conditions of high cognitive challenge. This study supplied further neural evidence that attention control during visual tasks is modulated by culture. Besides the activation in fronto-parietal regions, the suppression in default network regions was also affected by culture during tasks.

The results from RFT and FLT suggested EAs are more influenced by information from their surroundings than WCs. Nisbett et al. (2001) proposed that observers from collectivistic cultures are field-dependent, whereas individualistic cultural observers are field-independent (see also Ji et al. 2000; Norenzayan and Nisbett 2000). Field-dependence is defined as a relative difficulty in separating objects from the context where they are located (Witkin et al. 1962). It closely relates to the context-dependent attentional bias. Eye movement study investigating the distractor effect on saccade trajectories (Doyle and Walker 2001) also showed similar cultural bias (Petrova et al. 2013). When a distractor was presented, Chinese participants showed stronger curvature away in saccade trajectories than German participants (Petrova et al. 2013). This suggested that observers from a collectivistic culture exhibited stronger suppression of their attention towards distractors than those from an individualistic culture (Godijn and Theeuwes 2004; McSorley et al. 2004; Theeuwes and Van der Stigchel 2009; Tipper et al. 2001; Van der Stigchel and Theeuwes 2007).

One study using Navon stimuli attempted to directly quantify such contextual/global attention bias for collectivistic cultural observers. A Navon figure (e.g., large E made up of small Vs) is used as a standard stimulus in the attention literature to investigate global versus local attention bias. McKone et al. (2010) showed participants from different cultures Navon figures, and found that EA observers demonstrated a strong advantage over WCs.

Broad attention towards the surroundings might result from a better extra-fovea vision. For example, Boduroglu et al. (2009) asked observers from WC and EA culture to detect colour changes in a set of moving blocks. They found that EA participants were better than WCs when the layout of the blocks was expanded to the periphery of a scene, and worse when it is shrunk. Instead, WCs detected central colour changes most effectively. This result suggests more efficient parafoveal vision in EAs (Boduroglu et al. 2009).

Cultural attention bias has also been observed in electroencephalography signals. For instance, Lewis et al. (2008) used an ERP oddball paradigm to investigate the EEG activity of Europeans, Americans and Asian Americans to novel stimuli. Compared to European Americans, Asian Americans showed greater amplitude on the P3 component, which has been consistently associated to novelty detection (Debener et al. 2005; Ranganath and Rainer 2003). Taken in conjunction with the aforementioned behavioural findings (i.e. greater attention to contextual details for EAs), these results suggest that relative to European Americans, Asian Americans are more surprised when presented with a novel stimulus, presumably as a consequence of processing perceptually discrepant events to a greater extent.

In summary, culture shapes our visual experience. Even when the visual system is receiving identical input from the physical world, how the brain processes these input signal is influenced by cultural experiences. More importantly, these biases are likely adapted from the selective attention to different real world elements, and further merge into specific cultural perceptual tuning of different information. Indeed, much like real world stimuli could be decomposed into substances such as different categories of objects (including faces) and context information: certain abstract stimuli could be considered as constructed by smaller modules (e.g., features) or components (e.g., spatial information) in a similar way. Thus, culture shapes the human visual perception by regulating the information weighting to different components and the way these components interact with each other.

1.4 The Purpose of This Thesis

As shown in the previous chapter, a number of studies have showed systematic differences between East Asian and Western Caucasian observers in low-level perception and cognition. Culture affects how people are biased towards different information, which further modifies the correspondent brain areas. However, when and how culture influences the perceptual experience is yet to be clarified. Interpretation based on analytic-holistic cognitive tendency framework suggests that such bias is driven by attention to various kinds of information. Such hypotheses have suggested that culture diversity appears at an early perceptual stage. For example, selected visual information could be filtered by a top down effect depending on the culture of the observer. However, such perceptual selectivity and its neural correlate have never been directly observed with high temporal resolution methods. For example in the two studies using EEG, the cultural modifications seem to happen only in the later cognitive stages. It is worth noting that the limitation of the tasks should also be considered. The majority of the current cross-culture studies applied stimuli which are highly dissimilar in low-level visual properties (Petrova et al. 2013). Experiments only manipulated on the semantic level are unlikely to reveal any early effect (e.g., Goto et al. 2010).

Therefore, in this thesis, I aim to investigate the temporal modification effect of culture. I conducted three experiments with two highly sophisticated techniques that provided accurate temporal resolution: fixational eye movement and event-related potential. Stimuli were spatially normalized faces and Navon figures, which control for the information content.

The first study uses fixational eye movement to assess when different cultural observers actively explore new facial information through microsaccades. Different facial locations were aligned with the fovea while presented during eye movement recording. Recent evidence shows that microsaccades relocate the gaze towards the spatial location of interest (e.g., Ko et al. 2010; Rucci et al. 2007). If the fixation strategy differences between East Asians and Western Caucasians are indeed driven by the visual tuning to different spatial frequency information, Western Caucasian observers should exhibit better facial recognition ability after microsaccades compare to East Asian observers.

The second study examined the electrophysiological response associated with the cultural fixational bias. Following the result in the first experiment, this study adopted a similar paradigm. Face stimuli were presented briefly on the screen during EEG recording to simulate a single fixation. Given that observers perceive different information in each facial position, this experiment directly assessed when the ERP response is sensitive to eye movement strategies. Belief presentation of face stimuli on preferred face viewing location should improve the behavioural response of face recognition, and further reflect in early ERP time-window especially N170.

The third and final study makes use of adaptation with Navon stimuli in EEG measurement. Adaptation (i.e., repetition suppression) is a well-established paradigm to evaluate the nature of information coding at the perceptual and neurophysiological levels. With Navon figures that control for local and global information, this study investigated when differential levels of repetition suppression (and thus sensitivity) across types of information in according to different cultures. Following the attention account of the early perceptual difference between WC and EA observers, different manipulations of local and global information should modulate the early attention-related ERP component (e.g., P1).

1.5 Methods

1.5.1 Eye Tracking

Eye tracking is a methodology to study oculomotor behaviour. As the most important organ of the human visual system, our eyes are never static. Human eyes are constantly moving to the most interesting location of the visual world. Benefiting from the optic properties of the eyeball, the visual world can be projected onto the retina in the surface inside the eye (Atchison and Smith 2000). The energy and information in the light is then converted into electrical and chemical signals by photoreceptor cells (i.e., rods and cones). Due to the differences in neurophysiological properties between the two and their respective distribution in the retina, the spatial resolution is not the same across retina location (Ryan et al. 2012). The fovea, which contains densely packed cones, is responsible for sharp central vision with maximum visual acuity (See Figure 1.5.1). However, central foveal vision covers only a very small portion of the entire visual field (normally subtends 2° of visual angle). To overcome such constraints, the human eyes are in constant motion to reposition the fovea to different part of the visual world (Duchowski 2007; Rayner 1998). By combining different characteristic eye movement measures (such as gaze location, fixation duration and saccade direction) with behavior or other psychophysiology measurements, vision scientists can infer what type of visual information is being perceived by the tested human observers.

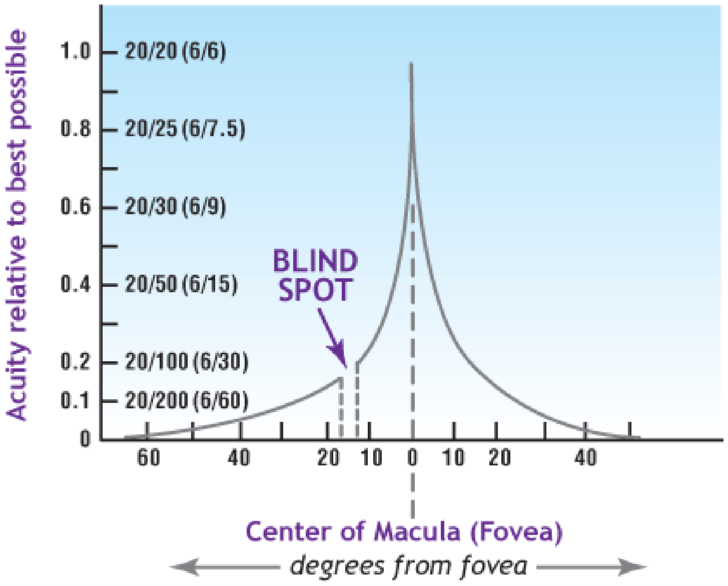

Figure 1.5.1, The relative acuity of the left human eye (horizontal section) in degrees from the fovea. Adapted from Hunziker (2006).

Different eye tracking techniques have been developed over the last 70 years since the first modern eye movement experiment was conducted (Buswell 1935). Three main eye tracking approaches are widely applied: Electro-OculoGraphy (EOG), scleral contact lens/search coil, and video-based eye-tracker (Duchowski 2007). A video-based eye tracker that combines pupil and corneal reflection is the most popular method, for its non-invasiveness and inexpensiveness. In a common video-based eye tracker setup, an infrared / near-infrared light source is placed at some fixed position to create stable corneal reflections. A video camera or specially designed optical sensor then records the position of the corneal reflection and the center of the pupil. The vector between the corneal reflection and the center of the pupil is computed to extract the differences in eye rotations. After a simple calibration, the changes in eye orientations can be transforming into gaze location on the screen. Although such two point references on the eye can separate eye movements from small head movements quite efficiently, head stabilisation is usually required by putting the participants on a head/chin rest or a bite bar.

Eye movement studies generate a large quantity of data with a combination of spatial and temporal information. The raw signal is characterised into different meaningful events: blinks, fixations, saccades/microsaccades, pupil dilation, smooth pursuits, etc. For most computer-based psychophysiological studies, fixations and saccades are the main variables of interest. Fixations are relatively static eye movements that stabilize the fovea over a small area of the visual environment. Approximately 90% of viewing time is devoted to fixations (Duchowski 2007; Irwin 2004). Saccades are rapid eye movements that reposition the fixation to a new location. The categorisation of eye movement events is usually established by velocity of the gaze location changes. The velocity of the signal is compared to an empirical threshold. Fixations are then defined as eye movement below the threshold, whereas saccades are defined otherwise.

Different properties of eye movement events are then analyzed depending on the research hypothesis. Vision researchers usually perform statistic analysis on the fixation location and duration. As for saccades/microsaccades, the latency, amplitude, curvature, orientation, and occurrence over time are the common dependent variables in eye movement studies.

Conventional fixation analysis uses a region or area-of-interest (ROI or AOI) approach. In such an approach, statistical testing is only carried out on the eye movement data within the predefined areas in the stimulus space. For example, the number of fixations or the mean fixation duration within the region is tested across conditions. Unless the visual input can be divided into clear, unambiguous discrete units, like in the case of reading, segmenting visual inputs into ROIs can be constrained by subjective evaluations (Caldara and Miellet 2011). Such bias and inconsistency in defining ROI compromise the potential to replicate findings across studies. Moreover, in some cases researchers define post hoc ROIs according to the actual data. Such usage of the same dataset for both selection and statistic analysis is inappropriate and runs the risk of “double dipping” (sees Kriegeskorte et al. 2009). To overcome these limitations, our lab has recently introduced a novel, robust, data-driven technique that does not require the a priori segmentation of digital images used as stimuli into ROIs: *iMap* (Caldara and Miellet 2011). *iMap* is a data-driven spatial analysis application originally based on statistic applications such as statistical parametric mapping (image statistic with spatial smoothing using Gaussian Kernel). Further details can be found in Caldara & Miellet (2011) and perso.unifr.ch/roberto.caldara/index.php?page=3

1.5.2 Electroencephalogram

The electroencephalogram (EEG) is one of the standard techniques employed by neuroscientists to investigate the neural responses related to various perceptual and cognitive phenomena. First tested on human subject by Hans Berger in 1924, EEG is now widely applied in both scientific and clinical fields. Although the spatial resolution of EEG is quite poor, its high temporal resolution (1 ms or better) and relatively low cost make it a popular brain-imaging technique.

Generally, EEG non-invasively measures electrical brain activity from electrodes at different locations on the scalp. Neurons convert and process information in the form of electrical and chemical signals. However, the electrical activity produced by a single neuron is too weak to reach the scalp (Kirschstein and Köhling 2009). Instead, when thousands or millions of neurons that have similar spatial orientation activate synchronously, the summation of electrical potential results in voltage difference on the human scalp (Nunez 2006). Moreover, electrical activity recorded by EEG electrodes is the summation of postsynaptic potentials, given that action potential is too brief (around 1 ms) to be sufficiently summed up. Cortical pyramidal neurons are considered as the main generator of EEG signal, due to their unique orientation (Kirschstein and Köhling 2009). Pyramidal neurons have long apical dendrites perpendicular to the cortical surface, which make them excellent dipoles in EEG signals. Figure 1.5.2 demonstrates how negative and positive deflections in EEG are generated by pyramidal neurons (adopted from Kirschstein and Köhling 2009). Overall, EEG records the total of excitatory and inhibitory postsynaptic potentials from a population of synchronous and partly aligned cortical neurons that extend over large areas of the cortical surface.

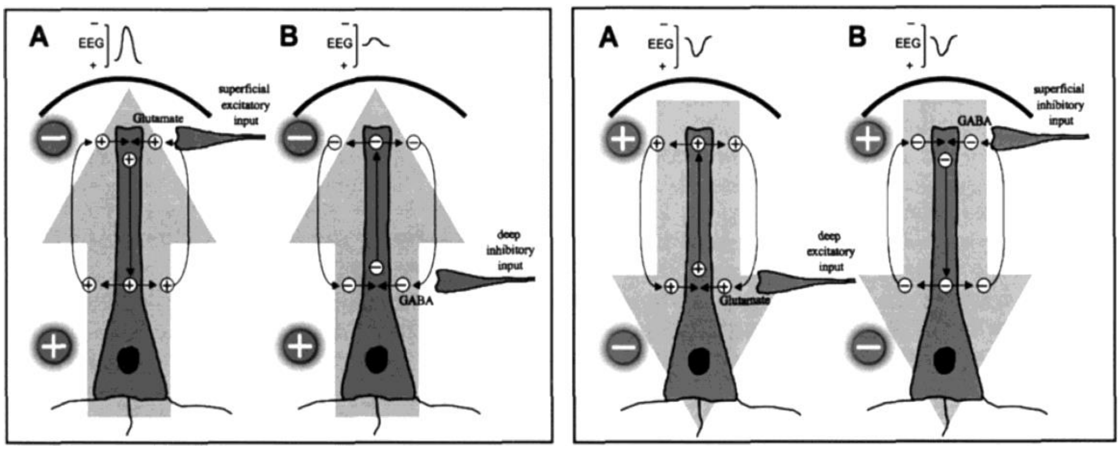

Figure 1.5.2, Origin of EEG signal. Superficial excitatory inputs (A) or deep inhibitory inputs (B) to the pyramidal neurons produce negative (upward) deflections, whereas deep excitatory inputs (A) or superficial inhibitory inputs (B) to the same neurons produce positive (downward) deflections. Adapted from Kirschstein, & Köhling (2009) with permission.

Electrocortical activity is recorded by electrodes placed on the scalp. Low resistance Ag/AgCl electrodes are positioned on an electrode cap or electrode net according to the international 10–20 system (Jasper 1958), which standardised the electrode position in relation to fixed markers of the skull (i.e. the nasion and the inion). While the number of electrodes being used depends on the experimental question, in modern EEG studies electrode number normally ranges from 32 to 256 (Schneider and Strüder 2012). Such an electrode cap or net is positioned on the head of the participant. Special gel is placed between the scalp and the electrodes to improve conductance.

During EEG recording, participants are usually required to limit head and neck movements, as these will produce undesired EEG artefacts. Eye movements from eye blinks and saccades are also a major source of EEG artefacts. In most vision experiments, participants are instructed to maintain their fixation on the center of screen. In the two EEG experiments of the current thesis, high-resolution binocular eye movement was recorded with EEG and processed online to ensure the criteria of stable fixation during the experiment. More details will follow in the next section.

The scalp electrical signal is then recorded at a desirable rate (256 to 2000 Hz) and transformed through a differential amplifier. The EEG signal represents the voltages difference between electrodes and a given reference. There are four types of referencing methods are mainly used. 1) *Single reference*: one designated reference electrode is placed and EEG signal is measured as the difference between each channel and the reference electrode; 2) *bipolar reference*: similar to single reference but two electrodes are used as reference; 3) *average reference*: the reference is defined as the average signal of all electrodes. 4) *CSD reference*: the reference is defined as power spectra computed from current source density (CSD). CSD is an implication of linear volume-conduction model (Nicholson 1973; Nicholson and Freeman 1975). It measures the strength of extracellular current generators underlying the recorded EEG without depending on predefined references. In the cases of single and bipolar reference, designated electrode/electrodes are usually placed in locations of low neuro-electrical activity (e.g., the nose or the earlobe). Average reference is favoured increasingly by EEG experts (Picton et al. 2000; Rosenfeld 2000). It can be considered as a virtual ground site in the brain, which represents the zero potential point (Paukkunen and Sepponen 2008).

The raw EEG signal then undergoes several pre-processing steps, such as filtering and artefact rejection, to remove noise generated by unwanted electrical activity. For example, pertinent artefacts can be identified and rejected using independent component analysis (ICA) or principle component analysis (PCA) (Romo-Vazquez et al. 2007).

There are many ways to analyze the pre-processed EEG data. For example, in time-frequency analysis EEG signal is transformed into predefined frequency domains to correlate with different neurocognitive function. In the current thesis I exploit one of the main EEG techniques: Event Related Potentials (ERPs).

ERPs are time-locked electrophysiological segments to an internal or external stimulus. They are observed after stimulus onset, and therefore are directly related to the presented stimulus (Nunez and Srinivasan 2006). The onset of a stimulus is usually defined as time zero. An epoch of arbitrary length is then chosen based on the research question and extracted from the continuous signal (e.g., from -100 ms to 500 ms in related to stimulus onset). In each trial the mean activity of the pre-defined baseline is then subtracted (e.g. from 100 ms before stimulus onset to 0), to fulfill the assumption that no task-related neural activity should be observed before stimulus onset (i.e., baseline correction). Noisy trials are rejected and further artefact correction could also be applied. Accepted trials are averaged according to experiment conditions. Depending on the hypothesis, a large number of events is normally required to increase the signal-to-noise ratio (for a recent review, see Pontifex and Hillman 2007).

The resulting averaged ERP waveforms are combinations of a set of positive and negative voltage deflections, usually referred to as ERP components. Depending on the polarity of the deflection, they are labeled as P or N (i.e. P for positive and N for negative) followed by a number referring to the latency of occurrence (usually in milliseconds). See Figure 1.5.3 for a standard procedure to extract the averaged ERP.

Classical ERP analysis is component based. The variables of interest are the amplitude and latency of each ERP peak. The peak of a component is defined as the most positive or most negative deflection point within a given time-window. The ERP latency is then measured as the occurrence of the peak. While the peak amplitude can be considered as the component amplitude, researchers sometimes also calculate the mean amplitude of a component by averaging all the time points of an arbitrary time window centerd on the peak. However, conventional analyses that focus on the pre-defined components are restrictive and potentially miss meaningful differences between components (Rousselet and Pernet 2011). For example, Schyns et al. (2007) demonstrated that component peaks might signal the end of a process instead of its information processing mechanism. Increasingly, the literature started to apply data-driven analysis at all time points and electrodes to investigate the effect over the whole ERP time course (Delorme et al. 2007; Pernet et al. 2011; Rousselet et al. 2008; Schyns et al. 2007, 2009; Schyns et al. 2011).

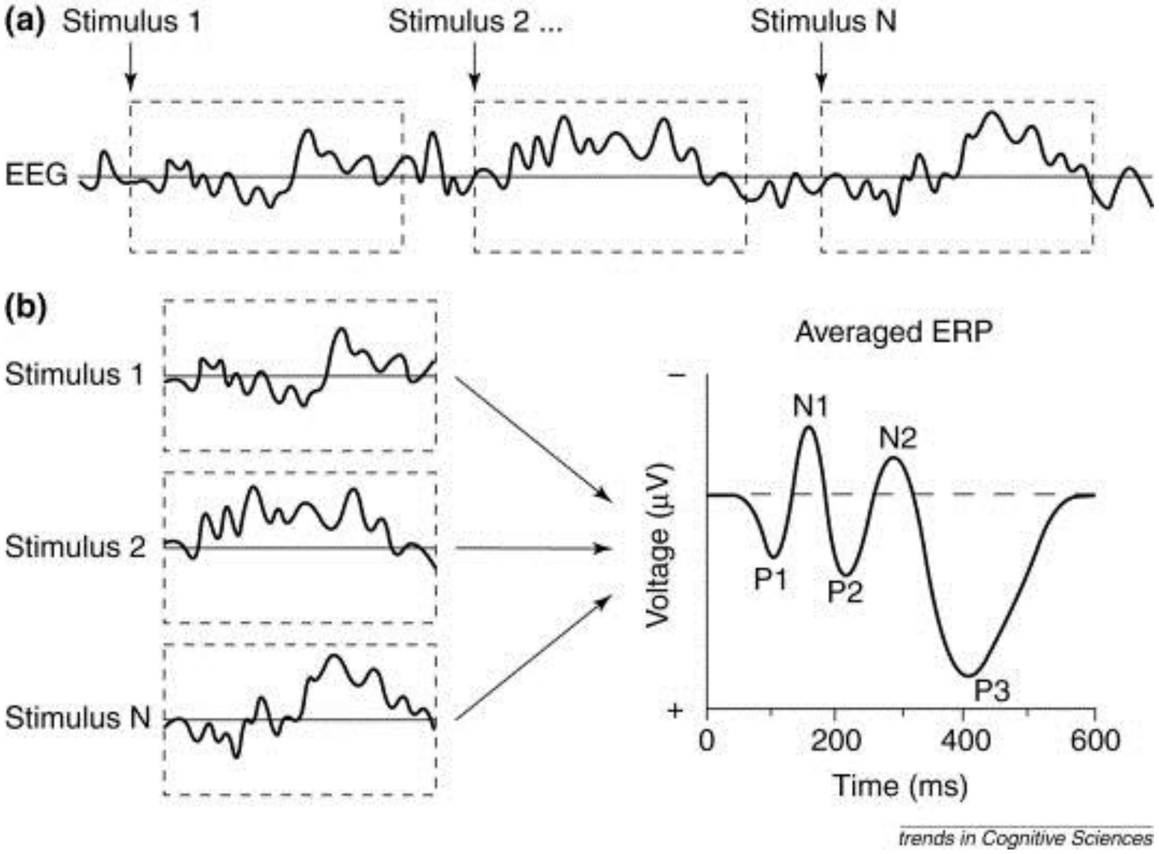

Figure 1.5.3, Example of extracting ERP waveform from the ongoing EEG signal. (a) Stimuli (1… N) are presented with ongoing EEG recording. The specific response to each stimulus is too small to be seen at single trial level. (b) EEG segments within pre-define epoch following each stimulus

are extracted and averaged together to create the ERP waveform. Adapted from Luck, Woodman, & Vogel (2000) with permission.

2 Microsaccades Boost Face Identification as A Function of Culture

Preamble

Human observers engage in different eye movement strategies to gather facial information depending on their cultural backgrounds. Free-viewing studies show that Westerners preferentially fixate on the eyes and mouth during face processing across a range of tasks, whereas Easterners allocate their gaze relatively more on the center of the face (Blais et al. 2008). Such divergence in fixation patterns has been demonstrated to be driven by the sampling bias for different spatial-frequency bands (Miellet et al. 2013).

Here, we further test the differences in cultural information tuning by registering microsaccades as an indicator of high-spatial frequency information sampling in an identification task. As the fastest and the smallest fixational eye movements, microsaccades enhance visibility of fine-spatial details during stable gaze (Martinez-Conde et al. 2013). Western Caucasian (WC) and Eastern Asian (EA) observers first learned eight face identities. We then examined the occurrence of microsaccades during identification of these identities while participants maintained fixation on the center of the screen. Nine equidistant Viewing Positions (VPs) were defined to cover the internal facial features. Face stimuli were aligned with a random VP centered with the fixation cross. Aligning participants gaze on the eye region elicited the highest rate of microsaccades and fastest identification response in both groups of observers. Crucially, WC observers showed optimal performance and highest microsaccade occurrence rate (400 – 500 ms) at their preferred viewing locations (as determined in the free viewing learning task). For EAs, fixation location preference predicts their microsaccade onset rate in the same time window, but not their behavioural performance. These findings show that the conjunction between preferred fixation location and high-frequency information is crucial to achieve optimal face identification performance.

2.1 Introduction

One of the most astonishing abilities human beings possess is face recognition. For example, we can determine a person's identity accurately within few fixations (Hsiao and Cottrell 2008) and across a wide range of viewing conditions (e.g., spatial scales, head orientations, lighting; Peterson and Eckstein 2012). Humans employ very sophisticated and consistent eye movement strategies to extract information from faces to accomplish various face-related tasks. Interestingly, these strategies are highly culture-specific (Blais et al. 2008; Caldara et al. 2010). For WC observers, their gaze follows a systematic triangular sequence of fixations to the eyes and mouth. This was revealed by the seminal work of Yarbus (1961) and confirmed in subsequent eye-movement studies (e.g., Althoff and Cohen 1999; Groner et al. 1984; Henderson et al. 2005). In contrast, recent researches have shown that EAs direct their gaze to the central area of the face (Blais et al. 2008; Caldara et al. 2010; Kelly et al. 2010; Kita et al. 2010; Miellet et al. 2013; Rodger et al. 2010). These culturally divergent oculomotor strategies are comparably efficient (Miellet et al. 2013), and consistent across different tasks (learning, recognition, categorization, etc).

Eyes and mouths contain the most diagnostic information for face processing (Davies et al. 1977; Gosselin and Schyns 2001; Rowley et al. 1998; Viola and Jones 2004). For example, visual information from the eye region is crucial for face identification and gender categorization tasks (Schyns et al. 2002). It is intriguing that the preferred fixation locations for EA observers are not aligned with the most informative facial features. To address this issue, Caldara et al. (2010) developed a novel gaze-contingent paradigm. In their experiment, a Gaussian "spotlight" was centered on the participant's fixation to restrict extra-foveal information. Their results showed that EAs' typical center fixation strategy disappears when extra-foveal information is unavailable, with participants instead exhibiting a scanpath identical to that observed for WC observers. This suggests that despite cultural diversity in eye movements, EA and WC observers universally rely on similar facial information to recognize faces. Furthermore, Miellet et al. (2013) employed a similar gaze-contingent procedure with a Gaussian "spotlight" that expands over time (i.e., dynamic spotlight). They then applied a retinal filter based on spatial frequency decomposition to reconstruct the visual information seen by participants. Their results showed that WCs preferably sample high-spatial frequency information from the eyes and the mouth with a local strategy. EAs on the other hand extract low-spatial frequency information from the same facial features with a global eye movement strategy. Together, these results reveal that fixation pattern variations between WCs and EAs are driven by differential spatial frequency tuning.

It is worth noting that the cultural differences in eye movement strategies and visual tuning are assumed to be relative matters of emphasis, rather than absolute differences of capability (Caldara et al. 2010; Miellet et al. 2011; Miellet et al. 2013). Indeed, observers can flexibly engage into local or global fixation strategies (Caldara et al. 2010; Miellet et al. 2012). Moreover, as shown in Miellet et al. (2013), EAs also fixate the eyes and mouth to obtain high resolution feature details. Thus, the importance of high-spatial frequency facial information, especially the contribution of such information across different facial locations, still remains unresolved.

To directly investigate this question, we developed a novel technique involving recordings of microsaccades to track the time course of high-spatial frequency information usage. Microsaccades are the involuntary microscopic relocations of gaze that occur during attempted steady fixation (for a review sees Martinez-Conde et al. 2009; Martinez-Conde et al. 2013). Although the precise perceptual function of microsaccades is yet to be clarified, recent evidences suggests that it may serve a similar role as saccades during exploration (Hafed et al. 2009; McCamy et al. 2012; Otero-Millan et al. 2013; Otero - Millan et al. 2011; Otero-Millan et al. 2008; Rolfs et al. 2008b). Crucially, microsaccades enhance the visibility of high-spatial frequency information by fine-tuning the retina position within fixation locations (Donner and Hemilä 2007; Ko et al. 2010; McCamy et al. 2012; Rucci et al. 2007). For example, Donner and Hemila (2007) showed that microsaccades might improve the retinal sensitivity to edges and spatial resolution.

Here, we investigated the temporal patterns of participants' fixational eye movements during a face identification task. Forcing WC and EA observers' fixations on various locations of the face (i.e. manipulating foveally processed information), we explored the dynamic interaction between cultural fixation bias, behavioural response, and the related microscopic oculomotor activity. Specifically, we compared microsaccade onset rates across cultures, while information was presented either at their non/preferred fixation locations. Given the tight relationship between local fixation strategy and high-frequency information usage in WCs, we hypothesized that they would benefit more from microsaccades than EAs. Regression analyses were conducted between fixation preferences, behavioural response, and microsaccade occurrence overtime. Our results indicate that, for both groups of observers, preferred location of fixations positively predicts microsaccade occurrence rate around 400-500 ms. Crucially, however, microsaccades that occurred within this time-window boosted face identification for WC, but not EA observers.

2.2 Materials and Methods

Participants

Nine WC (4 females) and ten EA (5 females) observers with normal or corrected-to-normal vision participated in the study. One WC and two EA participants were excluded from the analysis due to noisy eye movement recordings resulting from pupil occlusion. All EA participants were students from Sun Yat-Sen University, Mainland China; WCs were recruited in University of Fribourg, Switzerland. EA participants were tested by Dr. Lingnan He under a joint project between the psychology department of University of Fribourg and Sun Yat-Sen University. None of the subjects had previously participated in fixational eye movement studies, nor were they aware of the experiment's purpose. The study received approval of the respective local ethical committee (EA: Sun Yat-sen University Ethics Committee, WC: Ethics Committee of Vaud), and all participants provided written informed consent.

Stimuli and procedure.

WC and EA face stimuli were taken from the KDEF (Lundqvist et al. 1998) and AFID (Bang et al. 2001) databases, respectively. Faces were grey-scaled and aligned on the eye and mouth positions. Each image was 390 × 390 pixels in size, subtending around 10x10° of visual angle at a 70 cm viewing distance. Overall luminance was normalized using Matlab 7.5 (2007b); images were presented on a CRT monitor with a 800 × 600 pixel white background and a refresh rate of 120 Hz.

The subjects sat in a dimly lit, sound-attenuated booth. A head/chin support ensured maintenance of a constant viewing distance and prevented head movements. Participants were tested on two consecutive days. On the first day, they learned eight facial identities (2 races x 2 genders). Each identity was depicted displaying two emotional expressions (i.e. disgust, and happy) and assigned to one button on the keyboard. Participants learned to associate each identity to a specific finger by pressing the appropriate key. The stimuli were presented randomly at the center of the screen for 5 seconds each, with the corresponding response key displayed below. Throughout this process, participants could press the corresponding key freely to achieve an adequate level of familiarity and confidence. Subsequently, subjects performed a recognition task. The same face images were displayed (in blocks of eight trials, randomly depicting all identities encoded) at random locations on the screen until participants responded by button press indicative of facial identity. The memory task ended upon successful completion of at least 5 error-free blocks, 3 of which had to be completed consecutively. Throughout this initial learning phase, participants explored the stimuli freely while their eye movements were recorded. A drift correction was performed before each face presentation to ensure accuracy of oculomotor recording.

On the second testing day, participants were tested in the same room with the identical eye-tracking set-up. The stimuli presented included the previously learned identities as targets (displayed with neutral expression to ensure facial identification rather than image recognition) among 81 novel faces as distracters to increase task difficulty. Before the task began, the eight target identities (neutral expression) were presented for 2 minutes printed on a sheet of paper. Participants were instructed to identify target faces as accurately and as fast as possible, while ignoring (i.e. without providing button press response) distractor identities. Stimuli were presented at nine different locations on the screen. Based on the size of the face feature, we defined nine equidistant positions within the face (i.e. Viewing Positions – VPs) spaced by 2.24° visual angle (Figure 2.1a). The stimuli were then displayed with one of the nine VPs centered on the fixation cross. This procedure was to control for foveal and extra-foveal information sampling.

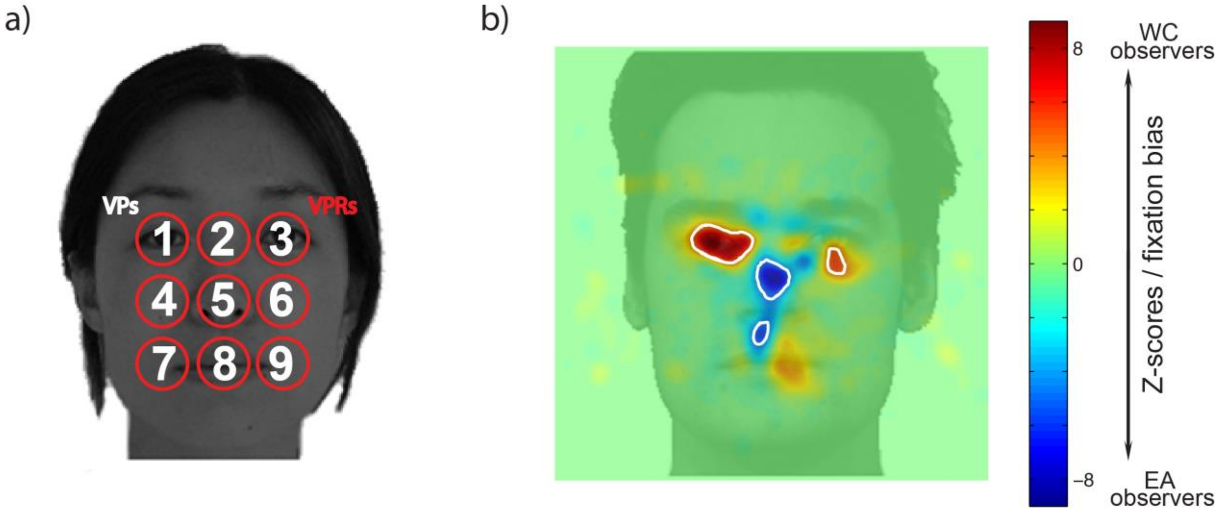

Figure 2.1, (a) Illustration of 9 Viewing Positions (VPs, white numbers) and the corresponding Viewing Position regions (red circles). Each region covers 1.6° of visual angle. b) The differential fixation map between the Western Caucasian (WC) and East Asian (EA) observers for the learning task (Day 1). The significant fixation bias difference is shown in the area delimited by white borders (Zcrit > |4.49|, p < .05, red for WC bias, blue for EA bias).

Each trial began with a fixation cross (0.2° of visual angle) displayed in the center of the screen for 500 ms, followed by the presentation of a face centered to one VP. The cross would not disappear during face stimulation to help the participant maintain their gaze. Stimuli remained on the screen until a response was provided for a maximum of 3000 ms for target faces, and 1000 ms for distractor faces. Trials were separated by a 500 ms ISI, with the subsequent trial automatically starting upon center fixation.

Participants were told to keep focus on the fixation cross at all time during the experiment. Stable gazing on the fixation cross was verified by eye-tracking. Participants' eye movements were monitored and processed on-line for trial validation. Trials containing blinks or saccades during face presentation were excluded. A trial was validated if the participants' eye drift was less than 2° of visual angle away from the center of the screen during stimulus presentation. The experiment ended when a participant completed 801 valid trials including 720 trials for target identities (8 faces × 9 positions × 10 times each position) and 81 trials for distracters (10% of the trials, 9 different faces at each position). See Figure 2.2 for a demonstration of the experiment procedure in day 2.

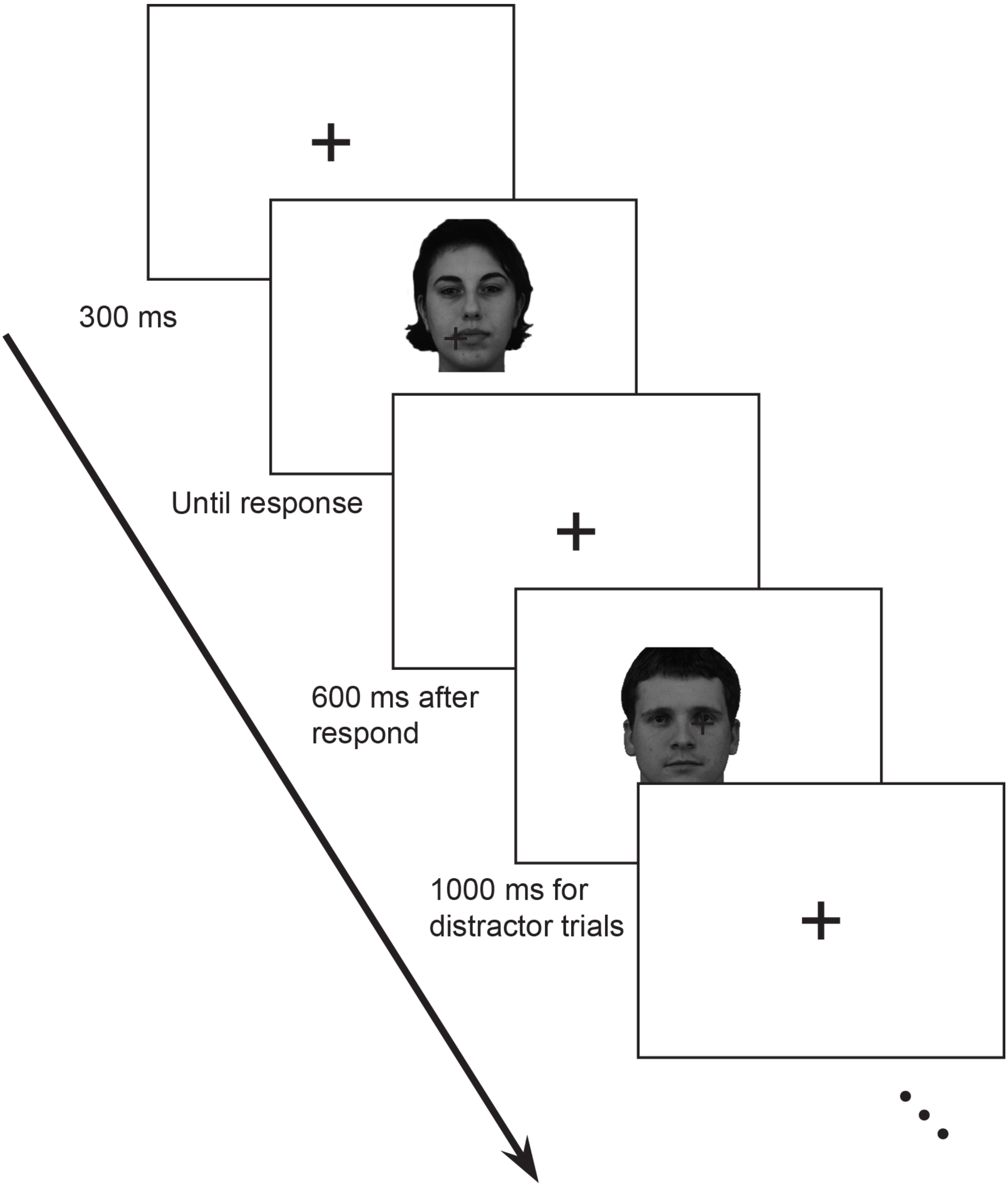

Figure 2.2, Experiment procedure in day 2.

Eye-tracking

Eye movements were recorded by means of Desktop-Mount EyeLink 2K eye tracker (SR Research Ltd., Mississauga, Ont., Canada) with a temporal resolution of 1000 Hz. We recorded binocular eye movements, but only the dominant eye position was used for on-line trial validation. The eye movement data were recorded via Matlab (R2006a), using the Psychophysics Toolbox (PTB-3, Brainard 1997; Kleiner et al. 2007) and EyeLink Toolbox extensions (Cornelissen et al. 2002). Calibration and validation of eye fixation were conducted before the experiment and repeated whenever necessary throughout the study.

Eye movement data preprocessing

Eye movement data sampled during face memory task on Day 1 included blinks, saccades and fixations. Blinks, as well as fixations outside stimulus area were excluded from the analysis. We then computed fixation duration maps individually for each observer in Matlab. Taking into account that more than 1 pixel is processed during one fixation, each fixation was smoothed with a Gaussian kernel (α=10 pixels) to represent the foveal area (2° visual angle). Individual fixation maps were computed by summing all fixation locations (x, y coordinates) across time for all trials. Moreover, to estimate each participant's fixation bias we first created masks of 1.6° of visual angle for each of the nine VPs. We then extracted the values of the fixation maps independently within each mask. To acquire the individual preference towards different VPs, we ranked the VPs for each participant by the value within the masks (i.e. Viewing Positions Ranks – VPRs).

Eye movement data collected on Day 2 were segmented into epochs from 0-1000 ms post stimulus onset. Analyses were restricted to valid trials for target faces (i.e. hits). Microsaccades were defined as outliers in 2D velocity space thresholded for peak velocity and minimum duration (Engbert and Mergenthaler 2006). We first computed eye movement velocity with a modified version of the central difference algorithm (Bahill et al. 1982; modified by Engbert and Mergenthaler 2006) to suppress high-frequency noise. We calculated the average of eye movement velocity within a moving time window (i.e. 10 ms). To detect microsaccades, we adapted the parameter implemented by Engbert and Mergenthaler (2006). Relativity thresholds were set independently for each participant as the outliners (five standard deviations away from the median) of the velocity values observed across the entire 1000 ms interval. Microsaccades were then defined where velocity exceeded a relative threshold for a minimum duration of six samples (6 ms). We only considered binocular microsaccades with a temporal overlap of at least two data samples (2 ms). Microsaccades were defined as saccades with magnitude <2° in both eyes.

2.3 Analysis and Result

Fixation map results

Group fixation maps were computed based on the individual duration maps from the face learning task from Day 1. Individual maps were summed separately per group to compute group-specific fixation maps. The mean and standard deviation of the fixation distributions of all observers were calculated and used to normalize the data. We then carried out a two-tailed Bonferroni corrected Pixel test (Chauvin et al. 2005) to assess locations significantly fixated by participants (iMap; see Caldara and Miellet 2011 for more details).

Consistent with previous results (Blais et al. 2008; Kelly et al. 2010; Rodger et al. 2010), WC participants preferentially fixated the eyes and mouth regions during face learning, while EAs predominantly fixated on the center of the face, mainly on the nose region. As shown in Figure 2.1b, the difference maps resulting from a two-tailed pixel test ($Z_{\mathrm{crit}} = |4.49|$ with threshold at $p = .05$) illustrate group-dependent differential fixation strategies. The effect sizes of the average fixation patterns per group were calculated using Cohen's *d,* which yielded $d = 1.13$ for eyes area for WC observers, and $d = 1.37$ for nose region for EA observers.

Behavioural results

The behavioural results are summarized in Figure 2.3. Mix model ANOVA and logit mix model regression are carried out on reaction time (RT) and accuracy rate (ACC) respectively. Essentially, the mix-model could be represented as:

$$\text{Behavioural measure} \sim 1 + \text{Groups\_of\_observers} + \text{VPs} + \text{Races\_of\_stimuli} + \text{Groups\_of\_observers*VPs} + \text{Groups\_of\_observers*Races\_of\_stimuli} + \text{VPs*Races\_of\_stimuli} \quad (1)$$

Result showed no significant main effects of *race of the stimuli* for ACC (SE = .024, $p = .078$) or RT (F (1,281) = .667, $p = .414$). Importantly, no significant interaction between *groups of observers* and *race of the stimuli* is revealed (ACC: SE = .013, $p = .051$; RT: F (1,281) = .314, $p = .576$). Although the impairment of recognizing other-race faces (i.e., other-race effect) has been widely report in the literature (e.g., Vizioli et al 2009 and 2010), in the current experiment only 4 target identities per race were presented. The relatively low task demand might account for participants' high performance on both races of stimuli. Moreover, given that our main focus is not on the other-race effect, the mix-model applied in the following analysis is simplified as model (2) with the race of the stimuli as a random effect:

Behavioural measure ~ 1 + Groups_of_observers + VPs + Groups_of_observers*VPs + (1 + Races_of_stimuli + Groups_of_observers*Races_of_stimuli | subject) (2)

No significant main effect of *groups of observers* is observed for ACC (SE = .016, *p* = .324) and RT (F (1,14) = .501, *p* = .480). We did not observe main effect of *viewing positions* for ACC (SE = .003, *p* = .744). Both WCs and EAs were comparably accurate (94.2%, 95% CIs [93.4%, 95.1%] for WC and 92.5%, 95% CIs [91.6%, 93.5%] for EA) regardless of the presentation location. We observed significant main effect of *viewing positions* for RT (F (8,112) = 15.892, *p* = 8.15e-5). No significant interaction was observed in ACC (SE = .002, *p* = .778) but RT (F (8,112) = 8.404, *p* = .004). Paired-sample t-test revealed that participants responded faster to the VPs on the upper part of the face (i.e., eyes and nose) than the lower part of the face (i.e., mouth) in WC but not EA.

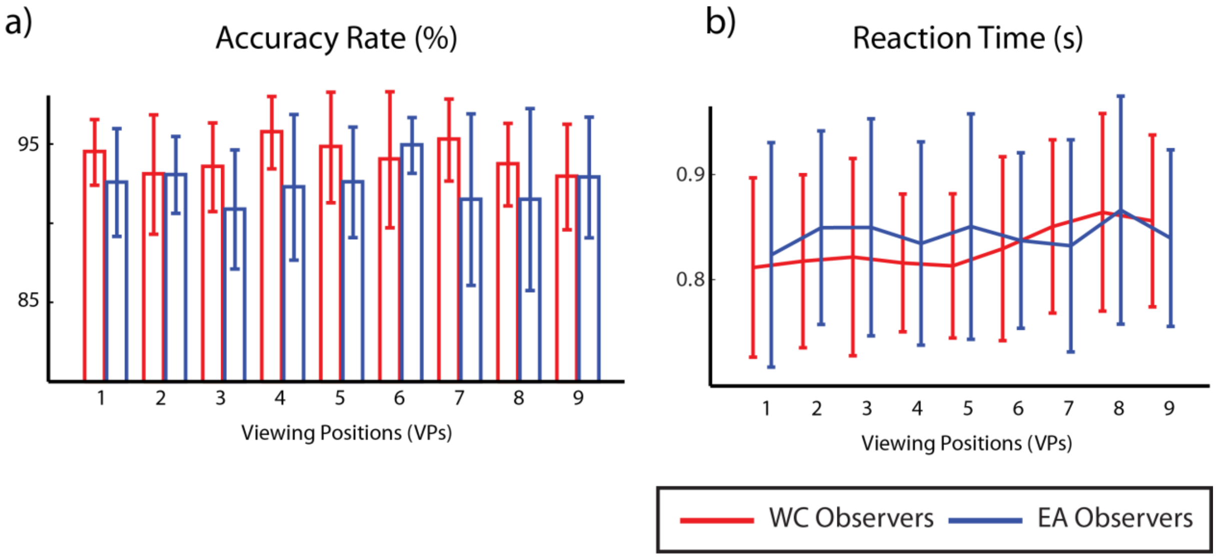

Figure 2.3, Behavioural results for the identification task on Day 2. (a) Accuracy rate and (b) reaction time for both Western Caucasian (WC, red line) and East Asian (EA, blue line) observers. All error bars indicate 95% CIs.

Microsaccade results

Figure 2.4a shows the time course of microsaccade onset after stimulus (target faces') onset for both groups of observers. The microsaccade occurrence rate of both groups of observers complies with the stereotypical time course with an early inhibition followed by a later increase (Engbert and Kliegl 2003; Rolfs et al. 2008a). The 2 (groups) × 9 (VPs) mixed model ANOVA on overall microsaccade occurrence rate revealed significant differences across viewing positions (F (8,112) = 3.668, *p* = .00078). Paired-sample t-tests showed that participant exhibited more microsaccades to the VPs on the upper part of the face (i.e., eyes) than the lower part of the face (i.e., nose and mouth). No significant group effect or interaction was found (Figure 2.4b). The microsaccade amplitude distributions of both groups of observers are shown in Figure 2.4c. The mean microsaccade magnitude of EAs was significantly larger than that of WCs (two-tailed independent t-test: *t* (2,15) = 24.5, *p* = 7.55e-7).

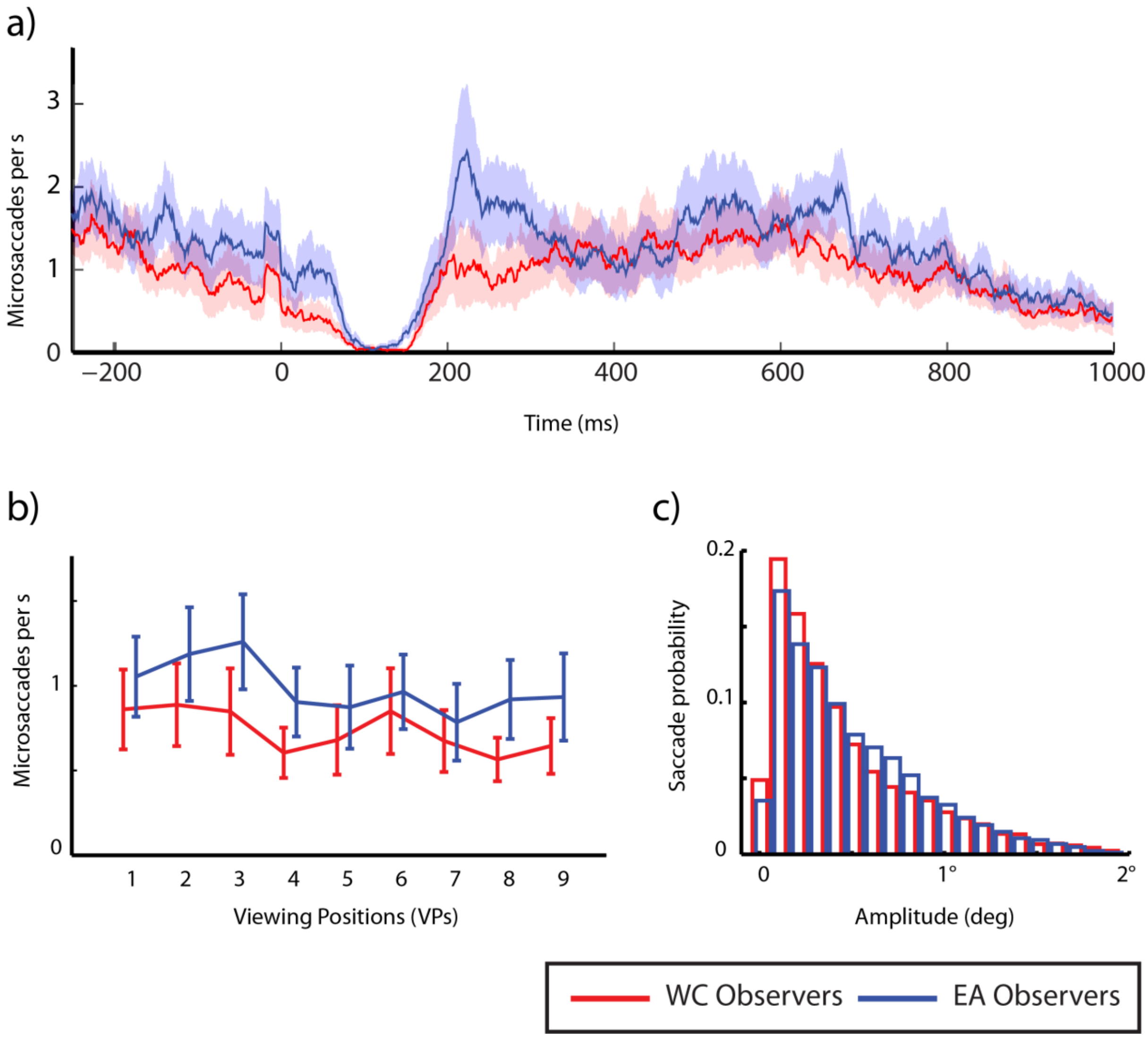

Figure 2.4, (a) Smoothed time course of the microsaccade onset rate of WC observers (red line) and EA observers (blue line). A 20 ms time-window moving average was applied as smoothing. Standard error at each time point is shown as shadow under the line plot. (b) Overall mean microsaccade onset rate for both groups of observers. (c) Distributions of microsaccade amplitude for WC (red) and EA (blue) observers.

Regression between viewing position preference, behavioural response, and microsaccade event

To fully explore the relationship between fixation bias, reaction time, and microsaccade onset rate over time, we first fitted a linear mixed-effects model then performed regression analyses independently per group of observer to further estimate different effect.

VPR and RT:

The reaction time and the fixation bias were first fitted into model (3). The reaction time was entered as respond vector and the main effects of *groups of observers* and *fixation bias* (VPRs) and the interaction effect between the two had been modelled. Noticeably, the *races of stimuli* and *the other-race effect* were controlled as random effect.

RT ~ 1 + Groups_of_observers + VPRs + Groups_of_observers*VPRs + (1 +
Races_of_stimuli + Groups_of_observers*Races_of_stimuli | subject) (3)

Result showed significant main effect of *groups of observers* (*b* = -.010, 95% CIs [-.015, -.003], SE = .003, *t* (284) = -3.041, *p* = .0026) and significant interaction between *groups of observers* and *VPRs* (*b* = .0057, 95% CIs [.0018, .0096], SE = .002, *t* (284) = 2.875, *p* = .0043).

To clarify the interaction effect and better estimate the coefficients of the fixation bias in each group of observers, a linear regression was performed using a robust regression approach independently for WC and EA observers. As shown in model (4), the reaction time was the respond vector and fixation preferences of each VP (VPRs) were entered as predictor. Moreover, to put the participants' behavioural response into the same scale, their reaction time was Z-scored.

Z (RT) ~ 1 + VPRs (4)

As shown in Figure 2.5, fixation bias (VPZs) significantly regressed with reaction time in WC observers (*b* = -.137, 95% CIs [-.193, -.033], SE = .04, *t* (70) = -2.818, *p* = .0063), but not EAs (*b* = .079, 95% CIs [-.00063, .159], SE = .04, *t* (70) =1.979, *p* = .052).

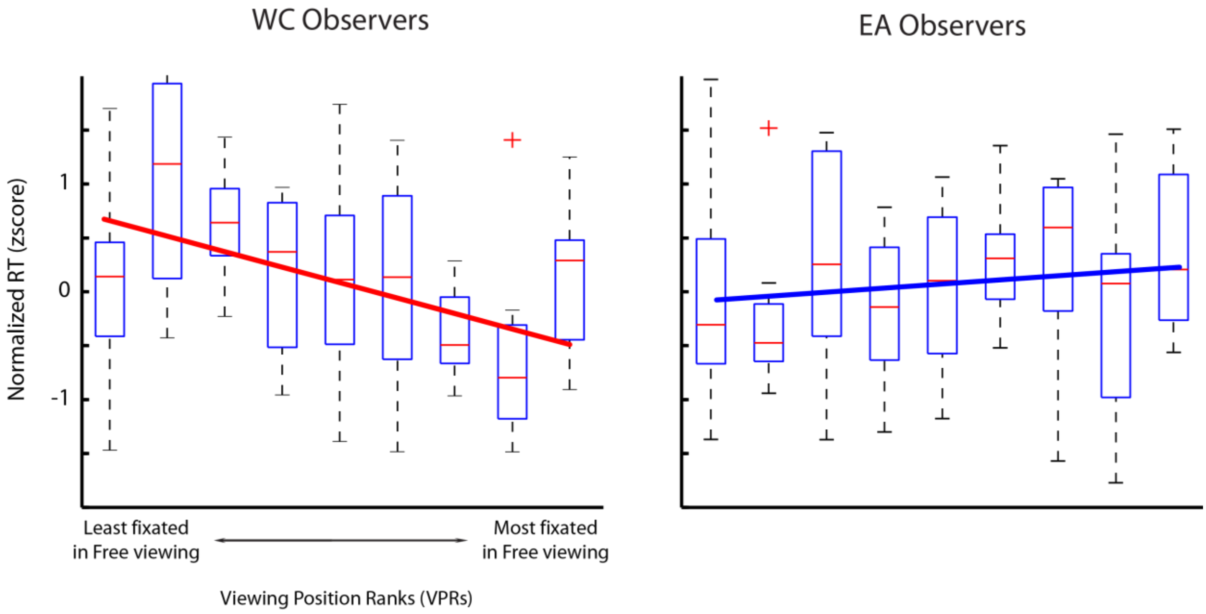

Figure 2.5, Regression results. We used VPR as predictor variable to regress with RT independently in WC observers (red line) and EA observers (blue line).

VPR and microsaccade onset: To understand the relationship between fixation preferences and microsaccade onset, we conducted linear regressions similar to model (4) using VPR as predictor variable to regress with microsaccade occurrence rate across the time course. Due to the discrete temporal property of microsaccade onset, conventional analyses usually consider its occurrence rate within some predefined time-window (Martinez-Conde et al. 2009). Here, we developed a novel method to parametrically sample microsaccade onset over time to study its temporal dynamics. Specifically, we divided the overall microsaccade onset time course (0-1000 ms post stimulus onset) into different numbers of time-windows (i.e., steps). Here, the number of time-windows we applied ranged from one (i.e., the whole time course, the first step) to 250 (i.e., four time points within each window, the last step). For each step, the microsaccade occurrence rate was calculated independently within each window and inputted into the regression as an output vector. We then conducted linear regressions using VPR as a predictor across all time windows independently for all the steps within each group. Such a method does not require subjective definition of a time window or temporal smoothing of the microsaccade onset rate.

To correct for false positives arising due to multiple comparisons, we used a multivariate clustering technique with bootstrapping (Maris and Oostenveld 2007; Vizioli et al. 2010; Wilcox 2005). Within each group, we first centered the microsaccade occurrence rate so that each condition had a mean of zero. We then used bootstrap to derive an estimate of the sampling distribution under the null hypothesis that no difference across the means was true. In each bootstrap, we sampled subjects with replacement and carried out the regression (as described above) independently at all steps and time-windows. We then grouped the significant F values ($p < 0.05$) into temporal clusters (Maris and Oostenveld 2007), considering only clusters with a duration >20 ms (maximum microsaccade duration). For each bootstrap, we computed the sum of F values in every cluster and selected the maximum cluster sum. We repeated this procedure 499 times, resulting in 500 F cluster sums for each main effect and the interaction. After sorting the 500 cluster sums according to their size, we selected the 95th percentile as the cluster threshold to assess statistical significance. The significant F values from the original regression were clustered, and the sum of F values inside each cluster was compared with the bootstrap cluster threshold for that test. A cluster was considered significant if the cluster sum was equal to, or larger than the threshold (Vizioli et al. 2010).

The results are shown in Figure 2.6. Fixation preference positively related to the microsaccade onset from 400-500 ms in both groups of observers. We found a significant regression in this time window, with increased VPR correlate with more microsaccade onset (WC observers: b = .058, 95% CIs [.030, .086], SE = .014, t (70) = 4.136, p = 9.67e-5; EA observers: b = .069, 95% CIs [.042, .095], SE = .013, t (70) = 5.189, p = 1.97e-6). Moreover, VPR also negatively related to microsaccade onset rate in the earlier time-course for EA observers. For example, we found less microsaccades at 200 – 300 ms on more preferred viewing position (b = -.302, 95% CIs [-.528, -.076], SE = .113, t (70) = -2.663, p = .0096).

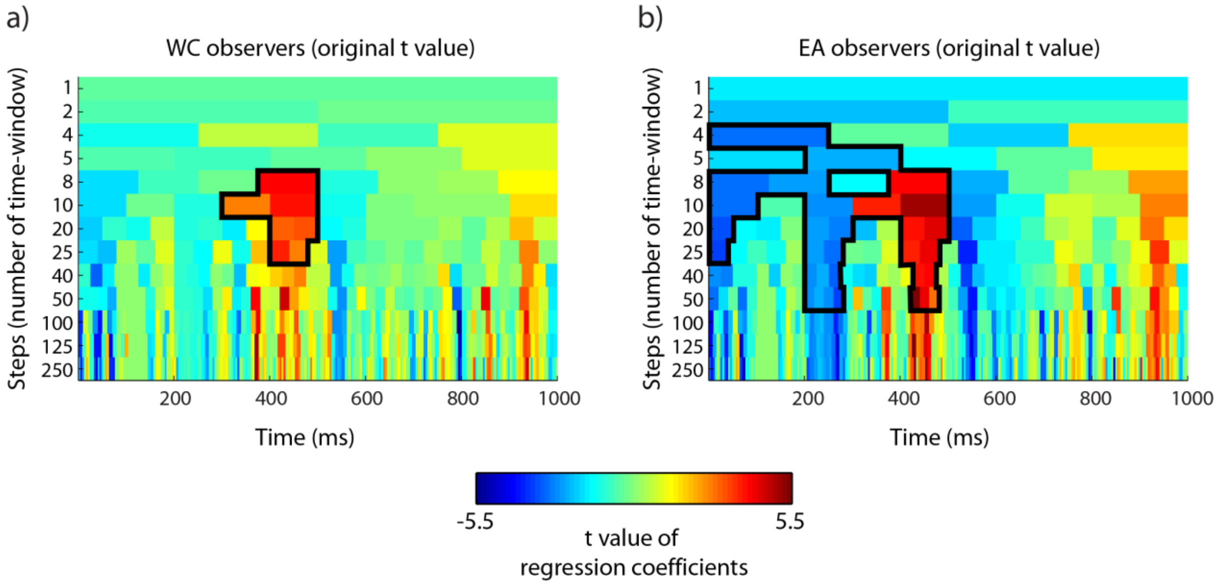

Figure 2.6, Regression between VPR and microsaccade onset rate. The x-axis shows the time in ms and the y-axis shows the different number of time-window being used in the current step. The value shows the t-statistic of the regression coefficients. (a) Original t value for WC observers. (b) Original t value for EA observers. The black line highline the significant t values for WC (a) and EA (b) observers. Multiple comparison corrections were conducted based on the significant F-statistic value of the model.

Microsaccade onset and RT: We determined whether and when microsaccade occurrence rate was related to reaction time by means of regression analysis. Microsaccade onset time course was binned in a similar way as previously described. We then carried out a regression independently per step using the microsaccade occurrence rate as the predictor, and reaction time as output. No significant temporal cluster was revealed after multiple comparison correction for EAs, indicating no relation between microsaccade occurrence rate and their behavioural response. For WC observers the increase of microsaccade onset rate in the 400–500 ms time window correlated with a faster behavioural response (b = -.834, 95% CIs [-1.479, -.190], SE = .323, t (70) = -2.581, p = .012), while the increase of microsaccade occurrence in the first 100 ms was related to a slower reaction time (b = .53, 95% CIs [.015, 1.048], SE = .259, t (70) = 2.054, p = .437). The result is showed in Figure 2.7.

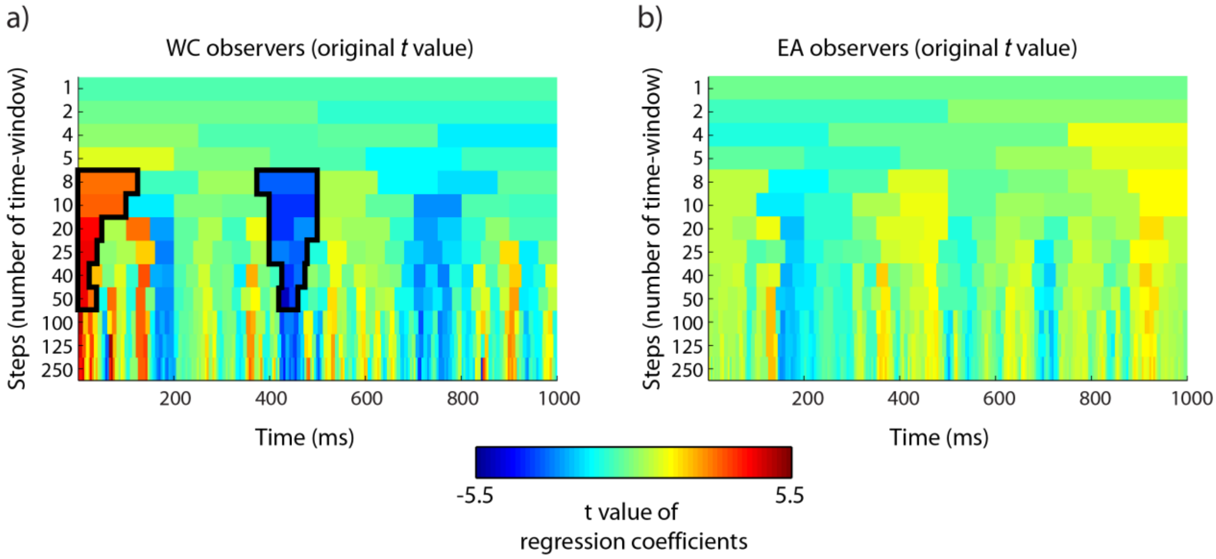

Figure 2.7, Regression between microsaccade onset rate and RT for WC observers. The x-axis shows the time in millisecond plotted against the different number of time-windows being used in the current step. The value shows the t-statistic of the regression coefficients. (a) Original t value for WC observers. (b) Original t value for EA observers. Significant is indicated by the black area. Multiple comparison corrections were conducted base on the significant F-statistic value of the model.

2.4 Discussion

The current study represents the first empirical evidence providing a direct link between local eye movement strategy and high-spatial frequency visual information during face identification. Here, we compared the recognition performance of observers from different cultures in a fixational eye movement design. Participants maintained their gaze on the center of the screen, while face identities were presented with different facial locations aligned to the fixation cross. Behavioural results showed that participants perform better when they fixated the upper compare to the lower part of the face, regardless of their preferred oculomotor strategy. Moreover, both groups of observers exhibited overall more microsaccades when they fixated the upper compared to the lower part of the faces. To understand the relationship between fixation strategy and high-spatial frequency information processing, we perform linear regression between fixation bias for different facial positions (obtained in the separate free-viewing face learning session) and the microsaccade occurrence rate. We found that microsaccade events occurring at 400-500 ms positively regress with fixation preference in both WCs and EAs. However, microsaccade events within this time window correlated with a faster behavioural response in WC observers only. These results together suggest that microsaccades boost face identification for observers who rely on a local information sampling strategy (i.e. WCs). WC observers rely on high-spatial frequency information from their preferred viewing location for face recognition.

Optimal and preferred point of fixation for faces as a function of culture

The result in the present study shows that fixating at the eye region is optimal for face identification, regardless of the cultures of the observers and the eye movement strategy they engage in. The eye region contains the highest visual information than any other face area. For example, gazing at just below the eyes optimize participant's behavioural performance across various tasks (Peterson and Eckstein 2012). Similarly, we found that WC subjects respond faster when they fixate the eye area than the lower part of the face. Thus, EA observers are likely not rely on fovea vision to perceive diagnostic information in the eye region

Moreover, we observed that fixating on the preferred viewing location has behavioural advantage for WCs only. WC observers respond faster on their preferred viewing position, whereas EAs respond equally well across all viewing positions. Previous result sampling only WC participants also reported similar results (Peterson and Eckstein 2012, 2013). The behavioural function of preferred viewing location is likely to be driven by differences in spatial-frequency information tuning between WCs and EAs. Specifically, EA observers prefer to sample low-spatial-frequency information via a global eye movement strategy (Miellet et al. 2013). They are able to perceive efficiently facial information from peripheral vision even when they are forced to fixate at points away from their preferred viewing location. Instead, fixating away from the preferred viewing location substantially degrades perceptual performance of WCs.

These results further confirm that the behavioural advantage on preferred viewing position in WC observers stems from their perceptual tuning to high-spatial frequency information. While both groups of observers exhibited more microsaccades on their preferred viewing position, WC observers only exploit the advantages conferred by the fine-detail enhancement following microsaccade to better recognize faces.

Functional microsaccade in face recognition

The possible origins of microsaccade have long been debated (e.g., Collewijn and Kowler 2008; Rolfs 2009). Different microsaccade generation mechanisms could be summarized into two hypotheses. The first hypothesis mainly accounts for involuntary microsaccade. It suggests that such microscopic oculomotor behaviour is produced by the physiological mechanism to prevent and/or counteract image fading (Ditchburn et al. 1959; Ditchburn and Ginsborg 1952; Martinez-Conde et al. 2006), as well as the exogenous (bottom-up) attentional shifts while attempting fixations (Rucci et al. 2007). The second hypothesis suggests that microsaccades are driven by the shift of covert attention during fixation maintenance (Cornsweet 1956; Engbert and Kliegl 2004; Hafed and Clark 2002). For example, pervious results showed that participants used microsaccade to precisely relocate their gaze for the task at hand (Cunitz and Steinman 1969; Ko et al. 2010). Interestingly, regardless of the potential different origins, the perceptual outcome of microsaccade is the same. As demonstrated in recent studies, microsaccade could enhance visibility during fixation (Martinez-Conde et al. 2006), counteract visual fading both foveally and peripherally (McCamy et al. 2012), and re-sharpen fine-spatial details for feature extraction (Donner and Hemilä 2007; Kuang et al. 2012). Here we make use of the perceptual consequence of microsaccade as a physiological marker to measure the cognitive processing of high-spatial frequency visual information. We observed that microsaccade occurrence rate is the highest on the eye region, which contains the most task relevant information for both groups of observers. Moreover, our results showed that WCs, with a high-spatial frequency information tuning, benefit more from the perceptual gain following microsaccades.

While the bulk of the empirical research on microsaccades focuses on the mechanism of microsaccade generation, the temporal dynamic of microsaccade remains surprisingly unexplored. Here, we observed that microsaccade onset within 400 to 500 milliseconds is critical for behavioural response and it is likely to be related to the amount of available information. No study has previously reported perceptual enhancement effect of microsaccade during 400 – 500 ms. A limited number of studies indicate that microsaccades are generated every 200 – 300 ms to provide a high-acuity “snapshots” of a visual scene (Otero-Millan et al. 2008; Uchida et al.

2006). However, further research is required to clarify the exact function of microsaccade in this time window.

In summary, the microsaccade results empirically confirmed the perceptual tuning of different cultural fixation bias. Results from visual information reconstruction indicate a high-spatial frequency information tuning for WCs during face recognition (Miellet et al. 2013). Here, by directly comparing the behavioural performance following microsaccade in WC and EA observers, we showed that a local eye movement strategy is indeed driven by a high-spatial frequency information tuning. WC observers, who employ a local eye movement strategy, achieve optimal behavioural performance on their preferred viewing location following the perceptual improvement produced by microsaccade.

Conclusion

Human observers elaborate face representations through diverse eye movement patterns. Driven by the preference to different parts of the spatial-frequency spectrum, observers engage in either a local or global strategies to sample information from various face parts. Here, we showed that WC observers make use of high-spatial-frequency information from their preferred viewing location for more rapid face identification, while no behavioural advantage is observed on their preferred viewing location in the EAs. Moreover, WCs benefit from the enhanced detail visibility following microsaccade on the preferred point of fixation. These observations confirm that culturally shaped fixation strategies are driven by perceptual preference to different spatial frequency information.

3 Tracking the Neural Tuning of Cultural Diversity in Eye Movements for Faces

Preamble

Eye movement strategies deployed by humans to identify conspecifics are not universal. When looking at faces, Westerners fixate the eyes and the mouth regions, whereas Easterners focus more on the center. However, the neural bases of this culturally Preferred Viewing Location (PVL) bias have never been directly investigated.

We simultaneously recorded eye movements and electroencephalographic (EEG) signals of Westerners and Easterners while they performed face identification of learnt identities. To avoid EEG artefacts generated by saccades, we defined 9 equidistant Viewing Positions (VPs) covering all the internal facial features and presented faces centered on random VPs for 100 ms. The fixation maps extracted from a prior free-viewing condition corroborated cultural diversity in PVLs during face recognition. To directly isolate modulations of EEG signals as a function of PVLs, we first computed the ranking of fixation intensity for each non-overleaping VP regions (Viewing Position Ranks - VPRs). We then carried-out a component-free data-driven spatio-temporal regression between the VPRs and EEG amplitudes. This novel approach revealed a marked direct relationship between both measures at around 350 ms in all observers, which was not related to a burst of microsaccades occurring in this time-window. A data-driven pattern classification procedure associated the scalp topography of this effect with the topography of the well-defined face-sensitive N170 component.

Our data show that the distinct cultural fixation preferences for faces are related to a late universal post-perceptual tuning in the occipito-temporal cortex. Culture shapes visual information sampling, but does not regulate neural information decoding.

3.1 Introduction

Human beings make use of sophisticated eye movement strategies to extract visual information and effectively adapt to the environment. It is thus very intriguing that when processing the most critical biological stimulus – i.e. the human face – observers from different cultures markedly differ in their information gathering strategies. Westerners use a triangular sequence of fixations including eyes and mouth (Althoff and Cohen 1999; Groner et al. 1984; Henderson et al. 2005; Yarbus 1961). By contrast, Easterners deploy central fixations (Blais et al. 2008; Kelly et al. 2010; Kita et al. 2010; Rodger et al. 2010), while reaching comparable face recognition performance. Yet, the underlying neural mechanisms of this cultural perceptual tuning in preferred viewing positions (PVLs) have never been directly investigated.

The accurate temporal resolution of electroencephalography (EEG) posits this neuroimaging technique as the optimal candidate to track early temporal dynamics of information processing. With regards to face processing, a wealth of evidence highlights the importance of a specific time window spanning approximately from 140 to 180 ms after stimulus onset. The N170 is an ERP component peaking negatively at bilateral occipitotemporal electrodes, larger to faces compared to any other visual category (Bentin et al. 1996). Importantly, N170 amplitude modulations have been observed for facial features in isolation, with the largest amplitude increase elicited by the eyes, compared to nose and mouth (Bentin et al. 1996). However electrophysiological modulations to facial features in isolation do not necessarily relate to processes involved during natural viewing conditions. These effects could be simply related to visual completion processes engaged in the reconstruction of full-face information. More recently McPartland et al. (2010) reported larger N170 to eyes and mouth compared to the nose, thus arguing for differential impact of PVLs upon neural face processing. Crucially though, this study employed a passive task and did not track eye movements during EEG recording, therefore not controlling for fixation locations and individual differences in PVLs. Given this shortcoming, it is impossible to unambiguously conclude whether such N170 modulations are related to PVLs, leaving this question unresolved.

To this aim, we simultaneously recorded eye movements and EEG signals of Western and Eastern observers while they performed a face identification task. Tracking the eye movements during EEG recording ensured a perfect control of the fixation location, as well as the elimination of trials contaminated by microsaccades, a source of potential confound (Dimigen et al. 2009). Because multi-oriented saccades generate complex EEG artefacts, faces were briefly flashed on nine predefined equidistant Viewing Positions (VPs, see Figure 1a) covering all the internal features. Individual PVL were extracted from a prior free-viewing face identity learning session using eye-tracking. We then directly related the electrophysiological signals with the PVLs by applying a component-free data-driven spatiotemporal regression analysis between those measures. Our data show no sensitivity on the N170 component, but the presence of a universal post-perceptual occipitotemporal neurophysiological sensitivity to PVLs at 350 ms, which mainly involve the same generators as the N170.

3.2 Materials and Methods

Participants.

Twenty-four right-handed subjects (12 East Asians – EA and 12 Western Caucasians – WC), 13 of which (7 EA and 6 WC) female, with normal or corrected-to-normal vision (mean age 26.4) participated in the study. All the EA participants were Chinese and had never been to a western country before. The maximum duration of residence in the UK upon testing was less than 6 months. The experiment received the approval of the local ethical committee and all participants provided written informed consent.

Stimuli and procedure.

A total of 24 grey scale images of four EA and four WC identities containing equal numbers of male and female faces were obtained from the KDEF (Lundqvist et al. 1998) and AFID (Bang et al. 2001) databases. Each identity was portrayed twice as an emotional (i.e. disgust and happy) and once a neutral face. The images were 390 × 390 pixels in size, subtending 15.6° degrees of visual angle vertically and horizontally with the face cover about 10° degrees of visual angle in the visual field. Viewing distance was maintained at 70 cm by a chinrest, reflecting a natural distance during human interaction (Hall 1966). Faces were cropped to remove external features and aligned on the eye and mouth positions. After normalizing their luminance in Matlab 7.5 (2007b), images were presented on a Dell P1130 19” CRT monitor with an 800 × 600 pixel white background, and a refresh rate of 170 Hz.

The whole experiment was carried out over two consecutive days. During the first day only emotional faces were displayed. The subjects sat in a dimly lit, sound-attenuated electrically shielded booth. Participants were instructed to learn the 8 identities. Each identity was assigned to one button of a computer’s keyboard. Participants learned to associate each identity to a specific finger – ranging from the index to the little finger of both hands – placed on the appropriate key. The stimuli were presented, in a random order, at the center of the screen for 5 seconds each, with the corresponding response key being displayed below each face. Within the 5 seconds presentation time, participants were allowed to press the key paired to the identity displayed on the screen as many times as they needed to achieve an adequate level of familiarity and confidence with the response. Subsequently subjects performed a memory task where they were required to recognize the faces they had just learned by pressing the buttons associated to the identities. The memory task ended upon successful completion of at least 5 error free blocks, 3 of which had to be consecutively completed without mistakes. Each block consisted of 8 identities displayed once until behavioural response, in random order and at random locations on the screen. The participants could freely explore the stimuli while their eye movements were recorded. An eye tracker drift correction procedure was performed before each face presentation to accurately determine the eyes position.

In Day 2, participants were tested in the same room with the same eye tracking setting. Additionally, EEG scalp signal was simultaneously recorded (see *Eye Tracking and EEG recording* section for details). Importantly, the stimuli presented in day 2 represented the same previously learned identities, but this time all faces displayed a neutral expression. Before the task began, the 8 neutral faces were rendered available for 2 minutes on a sheet of paper. On paper, the faces measured 4 by 4cm. Participants were instructed to correctly recognize the faces by button press as described before as accurately and as fast as they could. The faces were presented at 9 different locations of the screen. Based on internal features, we defined 9 equidistant positions within faces (i.e. Viewing Positions –VPs, see Figure 3.1a) spaced by 2.24° visual angle. The stimuli were then displayed for 100 ms with 1 of the

9 VPs centered on the fixation cross. By implementing this procedure we controlled for foveal and extra-foveal information sampling.

Each trial lasted approximately for 2500 milliseconds. The procedure began with a 0.3° fixation cross in the middle of the screen, displayed for 800 ms. This was followed by the presentation of a face centerd on one VP for 100 ms, succeeded by a second fixation cross which remained on the screen until behavioural response. There was a 1200 millisecond delay after the participants' response, and the next trial started automatically upon fixation at the center of the screen.

To avoid complex EEG artefacts generated by saccades, participants were told to keep focus on the fixation cross at all time during the experiment. Stable gazing on the fixation cross was verified using eye-tracking. Participants' eye movements were monitored and processed on-line for trial validation. Trials containing blink or saccade during face presentation were excluded. A trial was validated if the participants' eye drift was less than 1° of visual angle away from the center of the screen during stimulus presentation. The experiment ended when a participant completed 720 valid trials (8 faces × 9 positions × 10 times each position).

Eye tracking and EEG recording.

Eye movements were recorded by means of a Desktop-Mount EyeLink 2K eyetracker (SR Research Ltd., Mississauga, Ont., Canada) with a temporal resolution of 1000 Hz, a spatial resolution of 0.01°of visual angle and an average gaze position error of about 0.25°. Eye movements were recorded binocularly, but only the dominant eye position was used for valid trials on-line processing. The eye movement data were recorded via Matlab (R2006a), using the Psychophysics (PTB-3) and EyeLink Toolbox extensions (Brainard 1997; Cornelissen et al. 2002). Calibration and validation of eye fixation were conducted before the experiment and repeated whenever necessary during the procedure.

The EEG data were acquired on a 128-channel Biosemi Active Two EEG system (Biosemi, Amsterdam, Netherlands), sampled at 1024 Hz. According to the 10-5 system (Oostenveld and Praamstra 2001), electrodes were placed in a nylon cap. Four additional electrodes (UltraFlat Active electrodes, Biosemi) were attached below and at the outer canthi of both eyes to record vertical and horizontal electro-oculograms. All electrode amplitudes were kept between ±25 μV. The ground consisted of an active electrode (common mode sense, CMS) and a passive electrode (driven right leg, DRL) forming a feedback loop for amplifier reference. Subjects were asked to minimize blinking, head movement, and other body movement.

Behavioural studies.

We applied mix model regression on reaction time (RT) and logit mix model regression on accuracy rate (ACC).

Eye movement data analysis.

During face memory task in Day 1 all identities fixation maps were computed individually for EA and WC observers using Matlab 7.5 (2007b). Blinks and fixations outside stimulus area were excluded from analysis. Taking into account gaze-tracking errors, each fixation was smoothed with a Gaussian kernel (α=10 pixels, corresponding to 0.4 degree of visual angle in the stimulus space). Individual fixation maps were computed by summing all fixation locations (x, y coordinates) across time for all trials. Moreover, to estimate each participant's fixation bias we first created masks of 1.6° of visual angle for each of the nine VPs. We then extracted the values of the fixation maps independently within each mask. To acquire the individual preference towards different VPs, we ranked the VPs for each participant by the value within the masks (i.e. Viewing Positions Ranks – VPRs).

We first computed the group fixation maps as the smoothed average fixation durations per pixel normalized in the stimulus space. Differences in fixation patterns across groups were then computed as a normalized contrast between EA and WC group maps. We then carried out a two-tailed Bonferroni corrected Pixel test (Chauvin et al. 2005) to assess the significant differences between the group fixation maps. For a detailed discussion on the novel approach used to analyze eye-movement data (*i*Map) see Caldara & Miellet (2011).

Eye movement data collected in Day 2 were segmented in epochs from -100 ms to 500 ms centered on stimulus onsets to maintain consistency with the EEG epoch. Trials with eye blinks and saccades with amplitudes >1° of visual angle were discarded from the microsaccade analysis (7 out of 720, <1%). Following the algorithms detailed in Engbert and Mergenthaler (2006), microsaccades were defined as outliers in 2D velocity space thresholded for peak velocity and minimum duration. We first computed the eye velocity with a modified version of the central difference algorithm (Bahill et al. 1982; modified by Engbert and Mergenthaler 2006) to suppress high-frequency noise. The eye movement velocity was a combination of vertical and horizontal movement components. Relativity thresholds were set independently for each participant as the outliners (five standard deviations away from the median) of the velocity values observed across the entire 600 ms interval. Microsaccades were then defined where velocity exceeded a relative threshold for a minimum duration of six samples (6 ms). Finally, we only considered binocular microsaccades with a temporal overlap of at least two data samples (2 ms).

EEG signal analysis.

Only trials with correct behavioural response were analyzed (96% for WC and 98% for EA, detailed in Result session). EEG signal was preprocessed using BESA 5.2 and further analyzed in EEGLAB (Delorme and Makeig 2004) and Matlab 7.5 (2007b). In BESA, EEG data were referenced off-line to an average reference, and low-passed filtered at 40 Hz with a slope of 6dB. We rejected noisy electrodes on a subject-by-subject basis and later interpolated them using the EEGLAB topoplot function. Activity due to eye blinks was removed from the data before segmentation using BESA built-in principal components analysis (PCA). To exclude possible artefacts from voltage drifts or amplifier saturation, we also discarded segments with absolute voltages larger than 120μV. Trials were averaged across epochs of -100 ms to 500 ms (614 time-points), independently per condition. For baseline correction, the average 100 ms of pre-stimulus activity was removed from every time-point independently at each electrode and condition.

To properly determine whether the neural activity measured with EEG was directly related to individually preferred viewing locations (PVL), we fitted different linear mixed-effect model and also conducted linear regressions to quantify the relationship between VPRs and EEG amplitudes. These analysis were applied to at all the electrodes and time-points independently in each group (Rousselet and Pernet 2011). To be consistent with the regressor, electrophysiological responses were also normalized based on the same logic. We Z-scored the ERP signal at each electrode and each time-point across all the participants independently. This analysis is a component-free data-driven method that makes no a-priori assumption about where and when to look for effects in the ERP signal. However, this method increases the likelihood of type I errors (false significant) due to the large number of comparisons.

To correct for multiple comparisons, we used robust statistic, including bootstrap (Wilcox 2005) and a multivariate clustering technique (Maris and Oostenveld 2007). Within each group, we first centered the ERP amplitude so that each condition had a mean of zero. We then used bootstrap to derive an estimate of the sampling distribution of our statistic in a condition in which the null hypothesis of no difference across the means was true. In each bootstrap, we sampled subjects with replacement and carried out the regression (as described above) independently at all electrodes and time-points. The significant F values ($P < 0.05$) were then grouped in spatiotemporal clusters (Maris and Oostenveld 2007). For each bootstrap, we computed the sum of F values in every cluster and selected the maximum cluster sum. We repeated this procedure 499 times, leading to 500 F cluster sums for each main effect and interaction. After sorting the 500 cluster sums, we selected the 95th percentile as our cluster threshold to assess statistical significance. The significant F values from the original regression were clustered, and the sum of F values inside each cluster was compared with the bootstrap cluster threshold for that test. If an observed cluster sum was equal or larger than the threshold sum obtained under H0, all of the time-points and the electrodes contained in that cluster were considered significant (Vizioli et al. 2010).

3.3 Results

Behaviour

Logit mix model regression is carried out on accuracy rate (ACC) with the following mix-model (1):

$$\text{ACC} \sim 1 + \text{Groups\_of\_observers} + \text{VPs} + \text{Races\_of\_stimuli} + \text{Groups\_of\_observers*VPs} + \text{Groups\_of\_observers*Races\_of\_stimuli} + \text{VPs*Races\_of\_stimuli} \qquad (1)$$

Based on the low difficulty of the task, we expected both group perform equally well with high accuracy rate. Indeed, result showed no significant main effects of *viewing position* (SE = .00176, p = .503) or *groups of observers* (SE = .00644, p = .054). We did not observed any other-race effect in accuracy rate as the result did not show significant interaction between *groups of observers* and *race of the stimuli* (SE = .00418, p = .938). As shown in Figure 3.1b, both WC and EA observers showed high face identification accuracy (WC: 96.3%, 95% CIs [96.0%, 96.6%]; EA: 98.1%, 95%

CIs [97.9%, 98.3%]) regardless of the viewing position. To increase the sensitivity of our analysis, only trials with accurate identification were considered in the following analysis.

A mix model ANOVA (1’) is applied on the reaction time (RT).

RT ~ 1 + Groups_of_observers + VPs + Races_of_stimuli + Groups_of_observers*VPs + Groups_of_observers*Races_of_stimuli + VPs*Races_of_stimuli (1’)

The result is shown in Figure 3.1c. No significant main effect or interaction is revealed. Especially, no significant interaction between *groups of observers* and *race of the stimuli* is revealed (RT: F (1,425) = .025, p = .874). To further quantify the relationship between fixation bias and reaction time, I fit the following linear mixed-effect model to the interested variables:

Z (RT) ~ 1 + Groups_of_observers + VPRs + Groups_of_observers*VPRs + (1 + Races_of_stimuli + Groups_of_observers*Races_of_stimuli | subject) (2)

Result showed significant main effect of *VPRs* (b = -.11, 95% CIs [-.218, -.006], SE = .00539, t (284) = -2.081, p = .038, see Figure 3.1d). To better estimate the coefficients of the fixation bias in each group of observers, a linear regression was then performed using a robust regression approach independently for WC and EA observers. As shown in model (3), the reaction time was the respond vector and fixation preferences of each VP (VPRs) were entered as predictor. Moreover, to put the participants’ behavioural response into the same scale, their reaction time was Z-scored.

Z (RT) ~ 1 + VPRs (3)

Regression result is shown in Figure 3.1e and 3.1f. Fixation bias (VPZs) significantly regressed with reaction time in both WC observers (b = -.137, 95% CIs [-.207, -.066], SE = .0357, t (106) = -3.823, p = .00022) and EA observers (b = -.075, 95% CIs [-.149, -.00044], SE = .0373, t (106) =-1.995, p = .049).

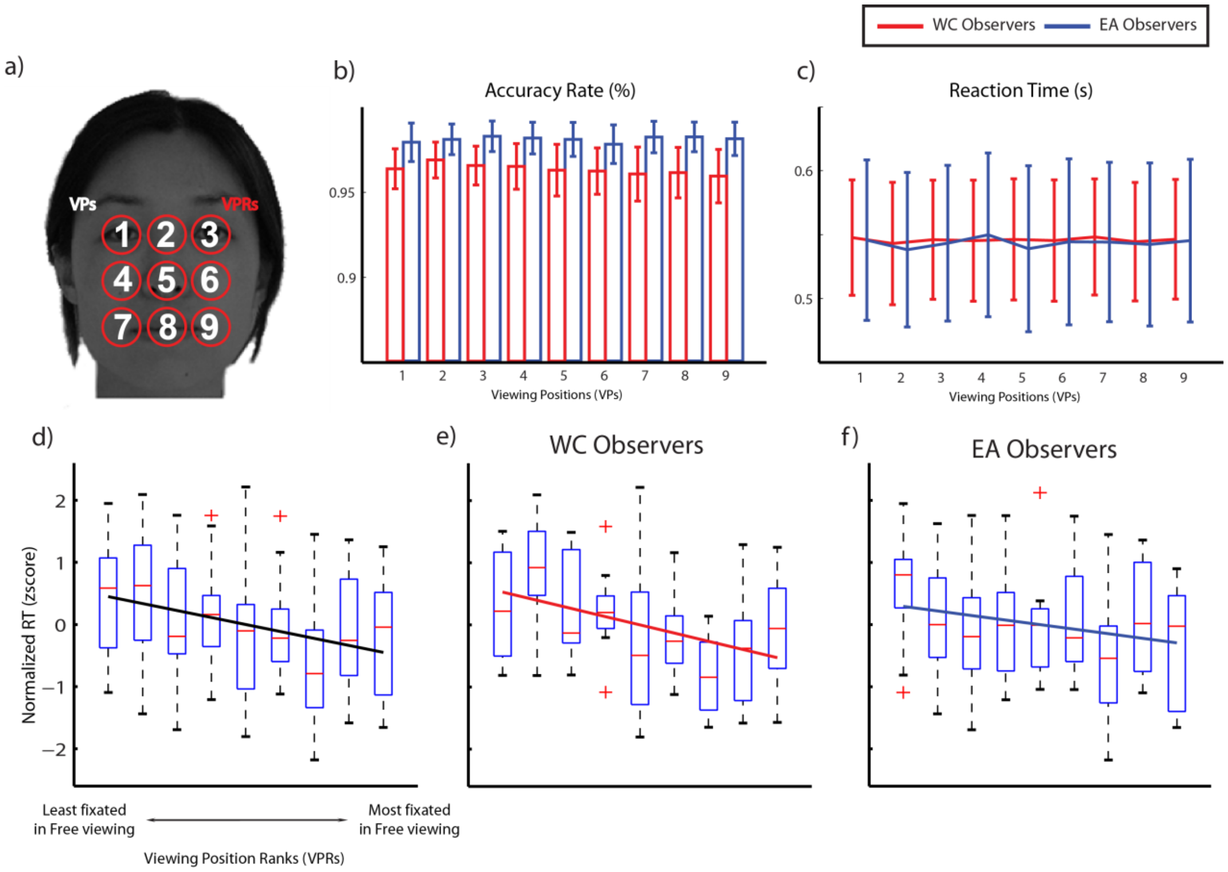

Figure 3.1. (a) Illustration of 9 Viewing Positions (VPs, white numbers) and the correspondent Viewing Position regions (red circles). Each VP region covers 1.6 degree of visual angle. (b) Accuracy rate for both Western Caucasian (WC, red bar) and East Asian (EA, blue bar) observers of the recognition task in Day 2. (c) Reaction time for both WC and EA observers. (d)Main effect of viewing position ranks (VPRs) in relate to normalized reaction time (RT) in liner mixed-effect model (2). (e) and (f) robust regression between VPRs and RT for both groups of observers. Error bars indicate 95% CIs.

Eye movements

Group fixation maps were computed based on the eye movement data collected in Day1. Consistently with previous results (Blais et al. 2008; Kelly et al. 2010; Rodger et al. 2010), WC participants preferentially fixated the eyes and mouth regions during face recognition. By contrast, EA participants predominantly fixated on the center of the face, mainly on the nose region. As shown in Figure 3.2c, the difference maps on which a two-tailed pixel test (Z_{crit} = |4.25| with threshold at p = .05) was applied clearly illustrated diverse fixation strategies across groups of observers. Figure 3.2a and 3.2b show the relative fixation biases per group. The areas fixated above chance are delimited by white borders (Figure 3.2c). The effect sizes on average fixation intensity between the two groups were calculated using Cohen's *d (d* = 2.31 for eyes and mouth region, and *d* = 2.43 for center region).

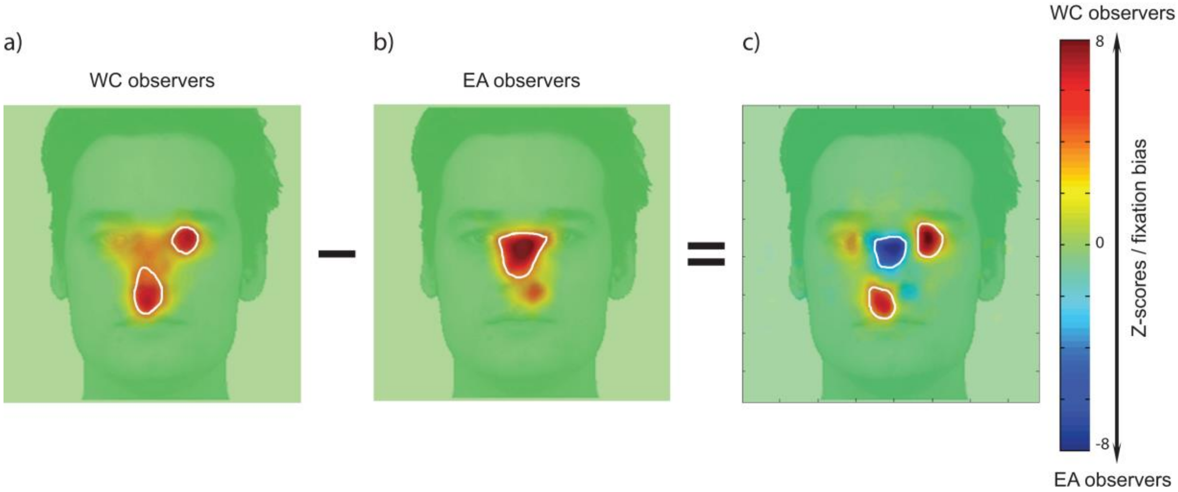

Figure 3.2. (a) Fixation maps for the Western Caucasian (WC) and b) East Asian (EA) observers in the learning task (Day 1). The white lines delimit areas significantly fixated above chance level. The differential fixation map (c) was computed by subtracting the WC (a) from the EA Z-scored group fixation map (b). A significant fixation bias in (c) is shown in the area delimited by white borders ($Z_{crit} = |4.25|$ with threshold at p = .05, red for WC bias, blue for EA bias).

Data-driven EEG analyses

Spatiotemporal linear mixed-effect model. Linear mixed-effect model was performed independently for all electrodes and all time points with normalized ERP amplitude as response vector and VPRs as input vector.

$$Z\,[\mathrm{ERP}_{(ie,\,tp)}] \sim 1 + \mathrm{Groups\_of\_observers} + \mathrm{VPRs} + \mathrm{Groups\_of\_observers}*\mathrm{VPRs} + (1 + \mathrm{Races\_of\_stimuli} + \mathrm{Groups\_of\_observers}*\mathrm{Races\_of\_stimuli} \mid \mathrm{subject}) \quad (4)$$

After multiple comparison correction, only significant main effect of VPRs is revealed in the time window of 330 to 380 ms (Figure 3.3a). Within this cluster, VPRs positively correlated with the normalized ERP amplitude over both occipito-temporal clusters (i.e., P7, P7h, P9h, PO5, PO7, PO7h, PO9h, PO9 on the left; P8, P8h, P10h, PO6, PO8, PO8h, PO10h, PO10 on the right, see Figure 3.3b), The largest effect was observed over PO8 at 357 ms: *b* = .219, 95% CIs [.176, .262], SE = .0217, *t* (284) = 10.069, *p* = 9.39e-20; the minimum effect was reported over P7 at 379 ms: *b* = .115, 95% CIs [.065, .164], SE = .0252, *t* (284) = 4.559, *p* = 8.65e-6.

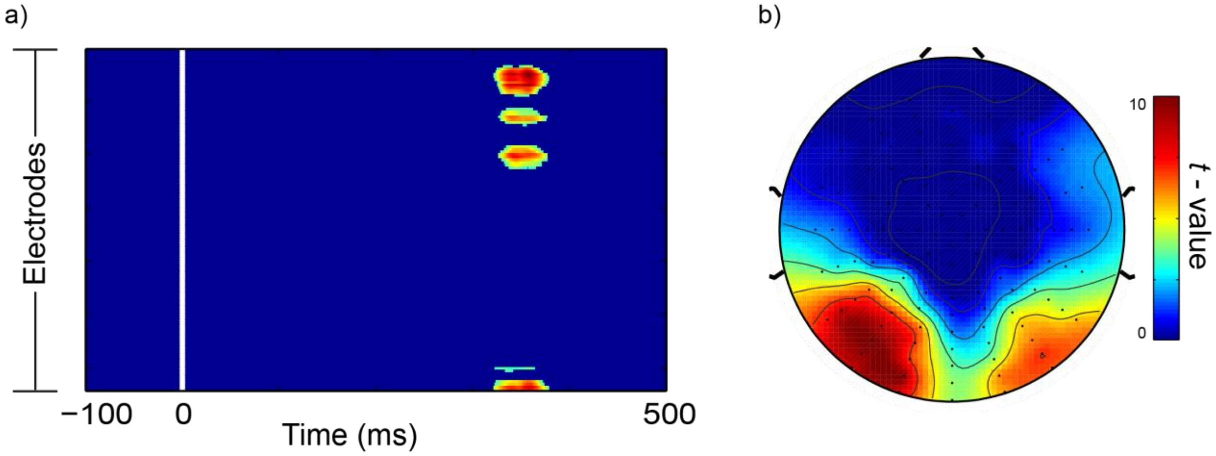

Figure 3.3. Spatiotemporal linear mixed-effect model results. (a) Significant t-value map of the VPRs main effect after multiple comparison correction. Electrodes are stacked up along the y-axis and time is shown along the x-axis. Statistical significant effects were found in 330 to 380 ms time window. (b)Topography of the VPRs main effect in this time window.

Spatiotemporal regressions. Within each group of observers, linear regression was performed independently for all electrodes and all time points with normalized ERP amplitude as response vector and VPRs as input vector.

$$Z\,[\mathrm{ERP}_{(ie,\,tp)}] \sim 1 + \mathrm{VPRs} \tag{5}$$

After multiple comparison correction, significant clusters were reported in both groups of observers in the time window ranging from 330 to 380 ms (Figure 3.4a & 3.4b, red panel). For clarity purposes, here we report only the statistical values of the electrode showing the maximal and the minimal effect within each cluster. VPRs significantly correlated with the normalized ERP amplitude over both occipito-temporal and center-parietal clusters (Figure 3.4g & 3.4i). On both sides of occipito-temporal cluster, VPR positively correlated with ERP amplitudes in both groups of observers (Figure 3.4h & 3.4j). For WC participants, the largest effect within the left cluster was observed over PO9 at 357 ms: b = .412, 95% CIs [.367, .463], R^2 = .263, F(1,80) = 34.538, p = 5.35e-4; the minimum effect was reported over P7 at 332 ms: b = .257, 95% CIs [.206, .300], R^2 = .067, F(1,80) = 6.936, p = .032. For EA participants, the largest effect within the left cluster was observed over P9h at 366 ms: b = .457, 95% CIs [.403, .510], R^2 = .367, F(1,80) = 61.375, p = 9.63e-5 and the minimum over PO8 at 377 ms: b = .291, 95% CIs [.217, .349], R^2 = .062, F(1,80) = 6.958, p = .045. Contrarily, on center-parietal cluster (Cz, C1, C2, CPz, etc.), VPR negatively correlated with ERP amplitudes. For WC observers: b_{max} = -.417, 95% CIs [-.462, -.368], R^2 = .172, F(1,80) = 21.954, p = 1.609e-6 and b_{min} = -.251, 95% CIs [-.305, -.199], R^2 = .062, F(1,80) = 6.947, p = .049. For EA observers: b_{max} = -.432, 95% CIs [-.489, -.372], R^2 = .217, F(1,80) = 29.393, p = 5.47e-6 and b_{min} = -.251, 95% CIs [-.305, -.199], R^2 = .062, F(1,80) = 6. 958, p = .048.

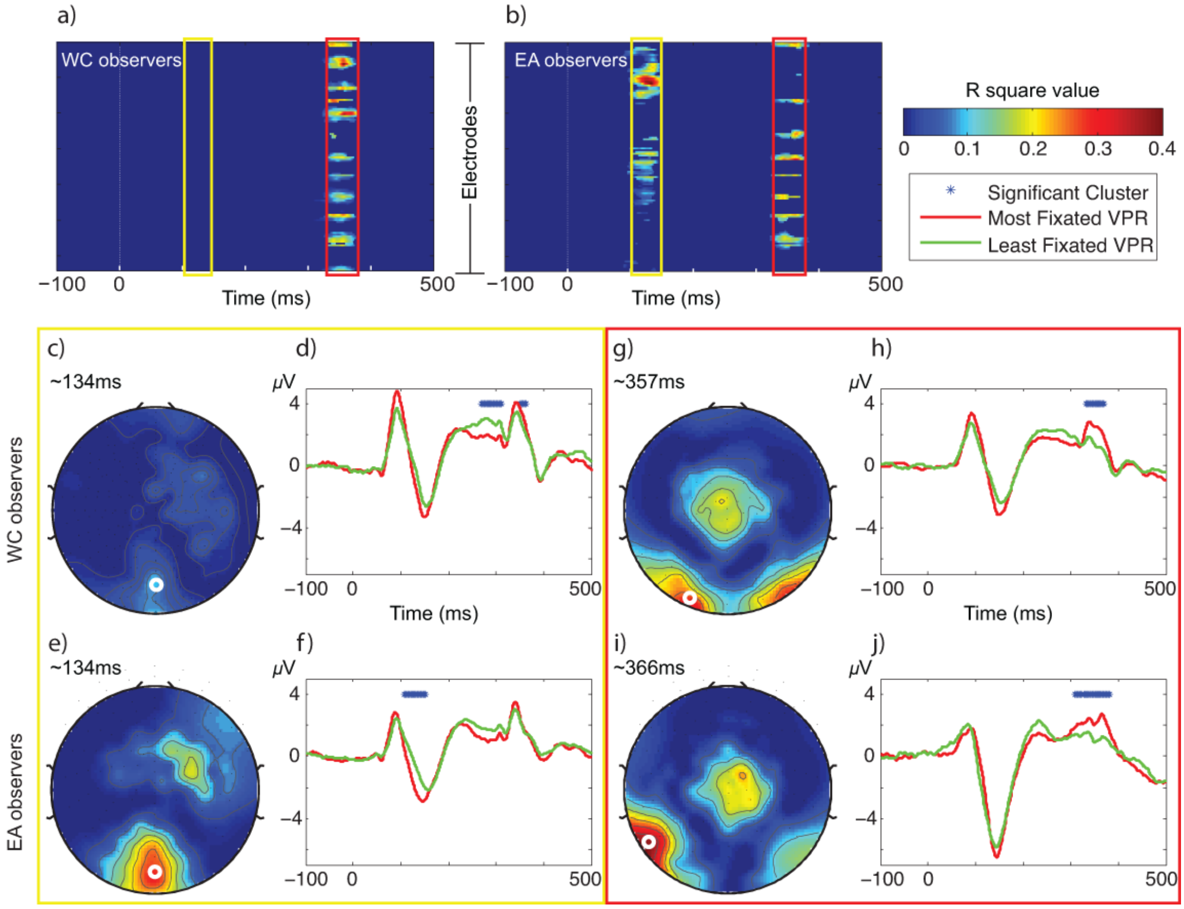

Figure 3.4. Spatiotemporal regression results for the Western Caucasian (WC, (a)) and the East Asian (EA) observers (b) after multiple comparison correction. Only significant clusters are shown. Electrodes are stacked up along the y-axis and time is shown along the x-axis. Statistical significant effects were found in two time-windows. Within the first, occurring at around 100 ms to 150 ms (yellow box), only EA observers show significant regression between Viewing Positions Region (VPR) intensity and normalized ERP amplitude (highlight as yellow). The second (red box) occurred at around 330 ms to 380 ms with consistent cluster burst in both groups. Topographies of both groups of observers at the latency of the maximum effect within each time window are shown accordingly in c), e), g) and i). Line plots of the original ERP are shown in d), f), h) and j) with only the most preferred VP (highest VPR intensity, red line) and the least fixated VP (lowest VPR intensity, green line) of selected electrodes (white circles shown in topographies, accordingly).

Moreover, a significant cluster in the time window ranging from 100 ms to 150 ms was observed at center-occipital electrode sites (i.e., POz, Oz, OIz, Iz, O1h, O2h) for EA observers only (Figure 3.4b yellow panel and Figure 3.4e). Regression results showed that VPR intensity were negatively correlated with normalized ERP amplitudes: b_{max} = -.527, 95% CIs [-.571, -.470], R^2 = .280, F(1,80) = 41.216, p = 1.44e-7 over Oz at 134 ms and b_{min} = -0.283, 95% CIs [-.331, -.227], R^2 = 0.079, F(1,80) = 9.148, p = .038 over POz at 103 ms; see Figure 3.4f.

Microsaccades

Figure 3.5c & 3.5d show the rate of microsaccades after the presentation of target stimuli along the ERP time course in both groups of observers. Previous studies showed that the microsaccade rate follows a stereotypical time course after sensory events, apparent as an early inhibition followed by a later rebound (Engbert and Kliegl 2003; Rolfs et al. 2008a). A similar result was observed here: after stimulus onset microsaccade occurrence decreased over time, to then increase after 200 ms, reaching a stable level at 300 ms.

To rule out the effect of microsaccade onset rate on our analysis, and especially the increase of microsaccade rate in the time window from 300 ms to 400 ms, we carried out a second level analysis on the spatiotemporal regression, taking microsaccade rate into account. After EEG signal preprocessing, but before averaging ERP epoch, the trials containing microsaccades on-set between 300 ms to 400 ms were excluded. This reduced the mean number of trials per condition to 56 (SD = 10.4). We then carried out the regressions between VPR intensity and the ERP amplitude again. As shown in Figure 3.5e & 3.5f, however, the pattern of result did not change.

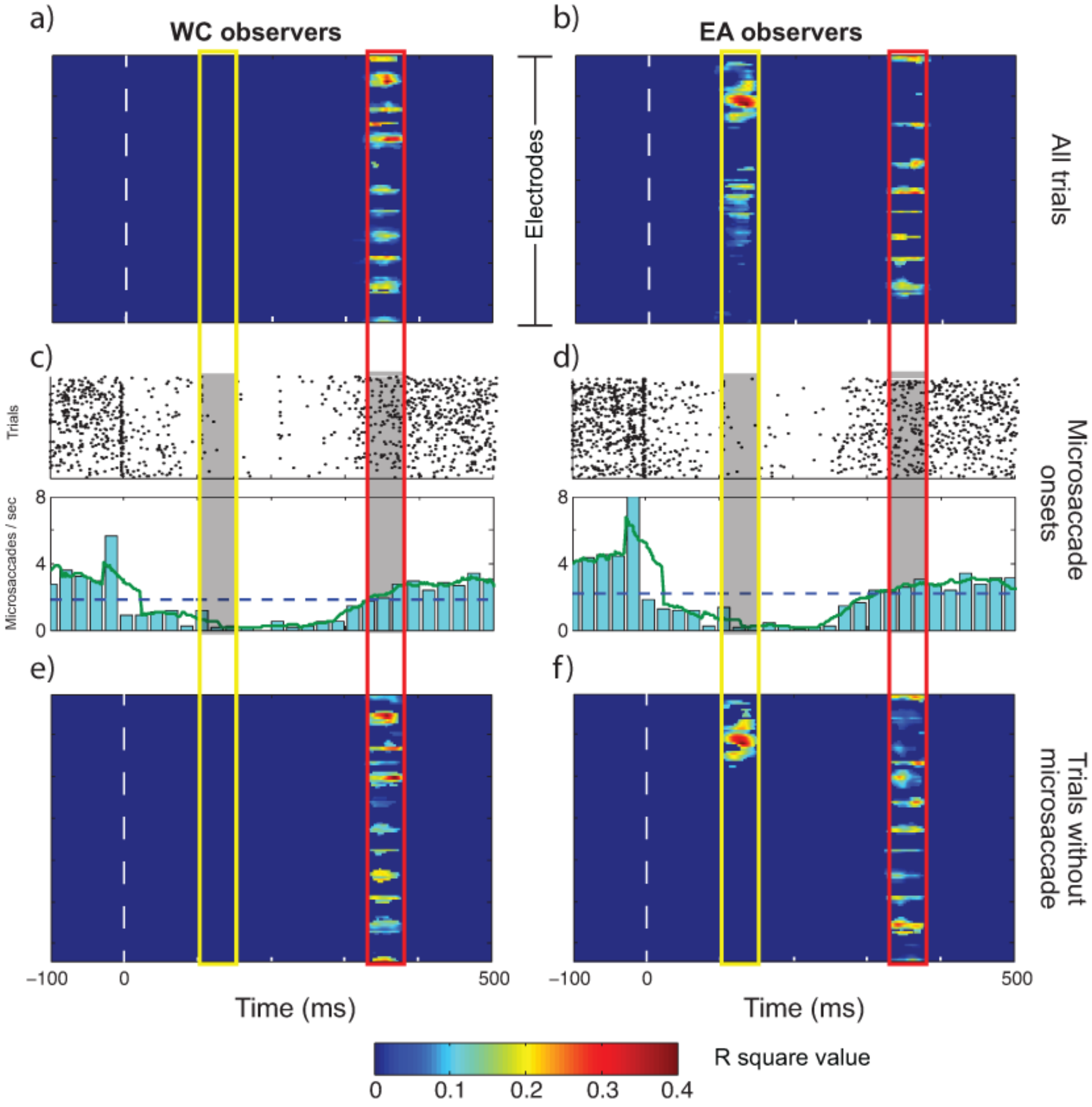

Figure 3.5. Spatiotemporal regression results before (a & b) and after (e & f) removing trials contenting microsaccades. Microsaccade onsets in all trials of each participant are displayed in the raster plots (c & d, top). Each row represents one trial. Microsaccades detected by binocular eye tracking are marked with dots. Histograms in the bottom of c) and d) represent the saccade rate (per second) calculated in 20 ms blocks. The green lines are reporting the smoothed time course of the microsaccade onset rate. The blue dashed lines across the histograms represent the mean rate across the whole epoch (-100 ms to 500 ms). The yellow panel and the red panel are indicating the time windows of the significant regression clusters.

Topography

To provide further insights on the neural correlates underlying activation pattern revealed by the regression, we computed Pearson's correlation between the topography of the beta weight obtained from the regression between VPRs and ERP amplitudes (which showed significant effects at roughly 350 ms – Figure 3.6a & 3.6d) with the original ERP topography of N170 (Figure 3.6b & 3.6e) and P300 (Figure 3.6c & 3.6f) components independently per group of observers. Beta topography correlated higher with the N170 topography (Pearson's correlation coefficient of WC observers $|r_{WC}| = .916$, $p = 8.21e\text{-}52$ and EA observers $|r_{EA}| = .798$, $p = 1.92e\text{-}29$) compared to P300 ($|r_{WC}| = .736$, $p = 3.95e\text{-}23$ for WC observers and $|r_{EA}| = .569$, $p = 2.47e\text{-}12$ for EA observers). Pearson's correlation between beta topography map and original topography is performed independently for all participants. Paired-sample ttest is performed on individual Pearson's *r* for each pair of comparison after fisher transformed. The correlation between beta topography and N170 topography is significantly higher than the correlation between beta and P300 topography (t (23) = 3.391, $p = .0025$).

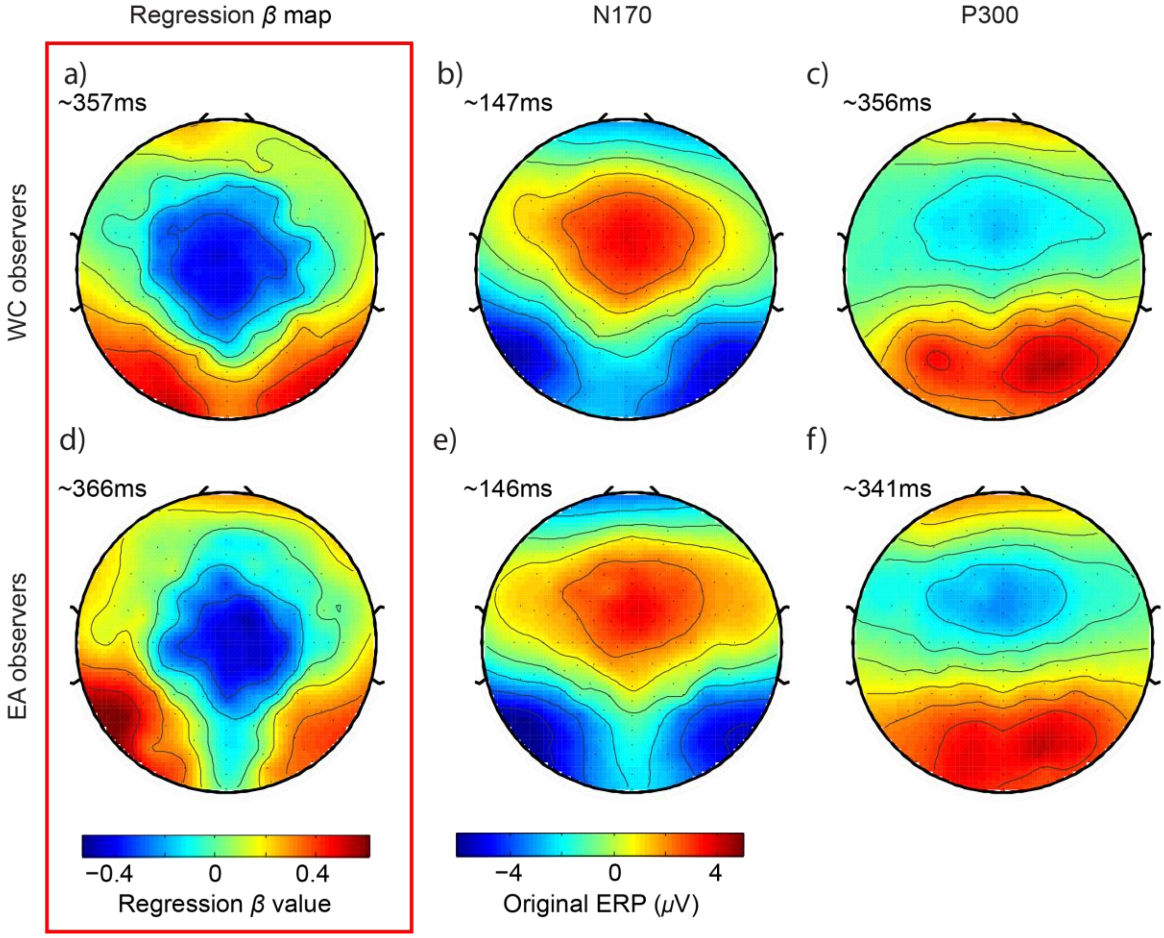

Figure 3.6. The topographies of the beta weight from the regression cluster at 357 ms for Western Caucasian (WC) observers (a) and at 366 ms for East Asian (EA) observers (d). b), e), c) & f) are the original ERP topographies of N170 (147 ms for WC observers and 146 ms for EA observers) and P300 (356 ms for WC observers and 341 ms for EA observers), respectively for WC (top row) and EA observers (bottom row).

3.4 Discussion

Culture alters the way people look at faces. Our data confirmed that Westerners preferentially fixate the eyes and mouth during face recognition, whereas, strikingly, Easterners focus more on the central facial region (Blais et al. 2008; Kelly et al. 2010; Kita et al. 2010; Rodger et al. 2010). Here, we aimed to isolate the neural dynamics of this perceptual, by using an original experimental design overcoming the EEG artefacts generated in the signal by eye movements. Regardless of the culture of the observer, brief fixation on Preferred Viewing Location (PVLs) increase participant's behavioral performance. Contrary to our initial expectations, the face-sensitive N170 was not modulated by the facial features presented on PVLs, or by the culture of the observers. In contrast, our data showed that the cultural contrast in PVLs for faces is *universally* coded by a distinct electrophysiological scalp response on the occipito-temporal cortex, occurring at about 350 ms in the time window of the P3 component. Interestingly, the topography enclosing the late sensitivity to PVLs was strikingly similar to the electrophysiological N170 topography and unrelated to a burst of microsaccades occurring in its time window.

Methodological contributions

There have been different attempts to combine eye movement and electrophysiological measures. Researchers either measured EEG and eye movements over separate sessions to then associate the averaged responses (Raney and Rayner 1993; Sereno et al. 1998); or recorded both measures simultaneously and correlated their signals (Dimigen et al. 2011; Nikolaev et al. 2011). In the latter scenario, fixation-related brain potentials (FRPs) are computed by averaging the electrical brain activity after saccade offset to isolate the contribution of the neural generator of saccadic movement to the ERP signals (e.g., Dimigen et al. 2011; Nikolaev et al. 2011). However, the implementation of this approach holds potential drawbacks, especially when investigating high-level neural responses to visual stimuli. Electrophysiological signals produced by neural saccade generators and those elicited by the stimulus at hand would concomitantly modulate the ERP signal, compromising the discrimination of the relative contribution of each of those two processes.

To overcome this limitation, we measured observers' fixation patterns in a separate free viewing face learning session. We extracted the fixation intensities in non-overlapping Viewing Position Regions (VPRs), as a measure of the individual preferences towards each Viewing positions. To directly link the eye movement and electrophysiological signals, we then simulated a single fixation by briefly presenting faces on 1 of 9 viewing positions and simultaneously recorded eye movements. We then performed a data-driven spatiotemporal regression between the VPR fixation intensities and the normalized ERP amplitude signals across all the time points and all the electrodes. In addition, following the recent concerns in microsaccade contamination of event-related EEG data (Dimigen et al. 2009; Yuval-Greenberg et al. 2008), we further carried out a confirmatory analysis by excluding the trials containing microsaccades.

Early and late electrophysiological responses of Preferred Visual Locations

P1 - We found a cluster of electrodes peaking at around 130 ms over the central-occipital site that was sensitive to PVLs in East Asian observers only. This observation might be accounted by a stronger sensitivity for processing faces with extra-foveal vision within this cultural group. In fact, we have recently shown that Westerners mainly rely on foveal vision, using mostly a relatively small (local) information span. In contrast, Easterners predominantly use a large information span, relying more on extra-foveal information while processing faces (Miellet et al. 2013). Since faces were mostly presented in diverse eccentric VPs, they most probably triggered a greater use of visual resources in Easterners, as the observers from this culture tend to extract global information from faces.

N170 - In the electrophysiological literature, the N170 has been established as being the major component showing sensitivity to faces (e.g., Bentin et al. 1996; Carmel and Bentin 2002; Rossion and Jacques 2008). Despite the N170 being clearly affected by various experimental and stimulus manipulations (Joyce et al. 2006), there is limited *direct* evidence in the literature that suggests that its amplitude is modulated by the facial features attended by the observers (but see the work of Schyns, 2003 & 2004). For example McPartland et al. (2010) showed that N170 amplitude was larger when participants gazed at the upper (i.e., between the eyes) and the lower part (i.e., mouth) of the face, compared to the central part (i.e., the nose). In the current study, we did not find significant modulation of the N170. The absence of an early electrophysiological effect on the N170 was surprising, yet not completely unexpected. To simulate genuine eye movement fixations to single features, we intentionally used faces covering a large visual angle (roughly 10° degrees). This is notably larger to what is routinely used in the electrophysiological literature (in general less than 7° of visual angle). Therefore, with this visual control it was not trivial for the observers to process all facial information from a single fixation, which might have engendered the necessity of going through a deeper stage of processing to retrieve the fine-grained representations of the facial identities. This observation is in line with previous studies, showing that the N170 amplitude was modulated by face images with task-related diagnostic information only on gender task but not on expression task (Joyce et al. 2006). In addition, unlike McPartland et al. (2010), here we used an active task. This factor could also account for the absence of an effect at this stage of face processing. More importantly, McPartland et al. (2010) did not consider the cultural bias in fixation preferences or directly took into account individual fixation preferences. This is an important drawback, as our active free-viewing condition clearly shows that every observer, even within the same cultural group, deploys a specific individual fixation pattern to achieve face recognition.

P300 - The novelty relies here. We found a distinct and strong linear relationship between both measures at around 350 milliseconds, on a cluster of bilateral and central electrodes of the occipital-temporal scalp. The more one region was preferentially fixated by an observer, the greater the electrophysiological amplitude responses on those clusters. This result remained unaltered after the removal of microsaccades, which indicated that this electrophysiological pattern is genuinely related to neural and not muscular activations related to micro eye movements.

The positive on-going amplitude occurring in this time window and its topography are in line with the P300 or P3b, a classical ERP component following the N170. The P300 is considered as a component reflecting decision-making process (Philiastides et al. 2006). Its amplitude is directly related to task demands, cognitive and perception workload (Kok 2001). Although P300 is usually not considered as face-specific, limited evidence suggests that it can be modulated by face processing (Liddell et al. 2004; Schupp et al. 2004; Streit et al. 2000), especially when an active task is involved (Campanella et al. 2000; Smith et al. 2004). For example Smith et al. (2004) showed that selective attention to diagnostic features and correct categorization modulated the P300 signal. In another example, the P300 amplitude was modulated by task complexity only when the participant was required to respond (Campanella et al. 2000).

Of particular interest, our data-driven classification procedure clearly associated the scalp topographies of our statistical regression effects to the surface activations characterizing the N170 electrophysiological topography for faces (and not the P300). This observation suggests that the neural activations modulated by the individual fixation preferences are most probably tapping into a neural network similar to the one recruited during the occurrence of the N170. Since the N170 has been associate to the brain regions dedicated to face processing (Sadeh et al. 2010), the P300 sensitivity to PVLs might be related to a re-entrant signal in the face system. This re-entrance for PVLs might reflect an access to fine-grained representations dedicated to decision recognition processes.

Regardless of this interpretation, the topography of the neural fixation bias for faces we identified here suggests that this phenomenon is most probably occurring in the occipito-temporal cortex instead of the frontal brain areas dedicated to the control of eye movements. However, due to the spatial resolution of EEG, further investigations are necessary to isolate the neural generators behind this effect and clarify the extent to which it would be related to the processing of faces, non-face visual objects and words.

3.5 Conclusions

Eye movement studies have shown that the preferred viewing locations for faces are different across East Asian and Western Caucasian observers. To isolate the neural responses underlying this cultural visual preference, we used a novel experimental design coupled with original robust data-driven analyses directly combining eye movements with electrophysiological signals over the time course. Our data show that the cultural perceptual bias is linked to a distinct universal electrophysiological response. Fixations towards the individual preferred facial regions elicit maximal bilateral occipito-temporal responses at around 350 ms, with a scalp topography very similar to the one typifying the face-sensitive N170 component. These findings provide unique evidence for a neural coding of eye movements for faces with an identical neural signature in every individual, most probably occurring in the occipito-temporal brain areas dedicated to face processing.

4 Culture modulates the Temporal Dynamics of Global/Local Processing

Preamble

Cultural differences in the way individuals from Western Caucasian (WC) and East Asian (EA) societies perceive and attend to visual information have been consistently reported in recent years. WC observers favor and perceive most efficiently the salient, local visual information by directing attention to focal objects. In contrast, EA observers show a bias towards global information, by preferentially attending elements in the background. However, the underlying neural mechanisms and the temporal dynamics of this striking cultural contrast have yet to be clarified.

The combination of Navon figures, which contain both global and local features, and the measurement of neural adaptation constitute an ideal way to probe this issue. We recorded the electrophysiological signals of WC and EA observers while they actively matched culturally neutral geometric Navon shapes. In each trial, participants sequentially viewed and categorized an adapter shape followed by a target shape, as being either: identical; global congruent; local congruent; and different. We quantified the repetition suppression (stRS), a reduction in neural activity in stimulus sensitive regions following stimulus repetition, using a single-trial approach. A robust data-driven spatio-temporal analysis revealed at 80ms a significant interaction between the culture of the observers and shape adaptation. EA observers showed sensitivity to global congruency on the attentional P1 component, whereas WC observers showed discrimination for global shapes at later stages.

Our data revealed an early sensitivity to global and local shape categorization, which is modulated by culture. This neural tuning could underlie more complex behavioral differences observed across human populations.

(This chapter has been published in Culture and Brain under the same title)

4.1 Introduction

Human visual experience is strongly modulated by culture. For over 20 years, cross-cultural research in cognitive science and, more recently in neuroscience, have shown that culture shapes the way we perceive the world (for a review, see Han et al. 2013). Studies comparing Western Caucasian (WC) and East Asian (EA) observers have provided convergent evidence on the cultural perceptual biases characterizing the cognitive styles of those populations (e.g., Nisbett and Miyamoto 2005; Nisbett et al. 2001). Westerners preferably focus on local information in objects (e.g., Masuda and Nisbett 2001), scene (e.g., Masuda and Nisbett 2006), and face perception (e.g., Blais et al. 2008; Caldara et al. 2010). In contrast, individuals from EA cultures – such as China or Japan - display instead a perceptual bias towards global information processing. Recent evidence has suggested that this cultural contrast might rely on culture-specific tuning towards visual spatial frequency information (Miellet et al. 2013). More precisely, WC observers use preferentially high spatial frequency information from foveal vision (e.g., see Miellet et al. 2013 for evidence from face recognition). In contrast, EA observers preferentially process contextual information by relying on extra-foveal vision during face recognition (Miellet et al. 2013), and for change detection of both low-level visual stimuli (e.g., color blocks; Boduroglu et al. 2009) and complex real-world stimuli (e.g., natural scenes; Masuda and Nisbett 2001).

These perceptual tunings have been related to attentional differences across cultural groups (Nisbett et al. 2001). In a series of studies, it has been consistently demonstrated that WC observers attend to and process more effectively local features, while EA observers exhibit a global attention bias (McKone et al. 2010; Nisbett and Miyamoto 2005; Hedden et al. 2008; Kitayama et al. 2003). For example, Kitayama et al. (2003) presented Westerners and Esterners a vertical line within a square frame and subsequently asked the observers to report the length of the line (i.e., rod-and-frame task). In the task requiring local selective attention (i.e., reporting the absolute length without referencing to the surrounding frame), WC observers are more accurate than EA observers, whereas EA observers outperformed WC observers in the task requiring global selective attention (i.e., reporting the relative length by referencing to the surrounding frame). EA observers are also more distracted by unrelated global information and faster at detecting targets at the global level compared to Westerners, (Boduroglu et al. 2009; Petrova et al. 2013), which suggest they might have a global selective attention bias. Within this framework yet, McKone et al. (2010) used Navon stimuli to directly quantify the global/local attention bias between Westerners and Easterners. Navon figures are hierarchical stimuli comprising a large global shape constituted by small local shapes (Navon 1977). One of the main advantages of these images lies in that participants viewing the very same stimulus (thus perfectly matched in terms of low-level visual properties) can be cued or can show a visual preference to either the local or global elements (McKone et al. 2010; Navon 1977). Interestingly, McKone et al. (2010) reported that only East Asian observers identified target letters faster when they were appearing at the global level. These authors attributed this performance advantage to a more effective global-selective attention in EA compared to WC observers (McKone et al. 2010).

However, the difference in attention selectivity between cultures has been questioned in a number of studies. For example, a direct replication of Kitayama et al. (2003) reported that both WC and EA observers performed better at tasks requiring more global- than local-selective attention (Zhou et al. 2008). Eye tracking results also showed that EA observers do not overtly direct more attention (i.e., fixations) towards the global information than WC observers (Evans et al. 2009; Miellet et al. 2010; Rayner et al. 2009; Rayner et al. 2007; but see Chua et al. 2005). In other cross-cultural studies using Navon figures, Caparos et al. (2013) tested observers from Himba culture (i.e. a remote culture from North Namibia, see Davidoff et al. 2008) and reported a perceptual bias to local features in this population. However, despite such very strong local perceptual bias, the Himba did not underperform on global selective-tasks compared to Western controls (Caparos et al. 2013). Altogether, the extent to which attentional processes are playing a key role on the cultural differences reported above and the presence of this perceptual bias across the Western and Eastern cultures remains to be clarified.

The electroencephalography (EEG) technique is highly relevant to probe this question and identify whether and when attentional processes would drive such cultural perceptual biases in global/local processing. Notably, attention modulates a particular electrophysiological signature in human observers: the P1 event-related potential (ERP) (Hillyard et al. 1973; Van Voorhis & Hillyard, 1977; for a review, see

Luck, Woodman, & Vogel, 2000). The P1 is a positive deflection peaking roughly 100 ms after stimulus onset on the occipital scalp surface, larger for attended than unattended information. Surprisingly, studies directly comparing two groups of observers did not reveal differences on this component (Goto et al. 2010; Lewis et al. 2008). For example, Goto et al. (2010) manipulated the semantic incongruity between objects and scenes. They only observed cultural differences in the ERP amplitudes at later stages of information processing (i.e., N400 components; Kutas and Hillyard, 1980; Holcomb and Neville, 1991). While methodological shortcomings such as significant differences in low-level visual properties of the stimuli should be taken into consideration (Petrova et al. 2013), conventional ERP analysis relying on absolute amplitude differences across conditions might not be sensitive enough to reveal early effects (see Vizioli et al., 2010). In order to increase the sensitivity of the electrophysiological signals, here we adopted one of the most powerful methods used in the neurophysiological literature, which relies on the neural repetition effect. Adaptation is a well-established paradigm used to reveal the nature of information coding at the perceptual and neurophysiological levels (for a review, see Grill-Spector et al. 2006). In this framework, "repetition suppression" (RS) is the reduction of neural activity, in stimulus-related regions, associated to the presentation of two or more stimuli in rapid succession (Grill-Spector et al. 2006; Henson 2003; Henson and Rugg 2003; Wiggs and Martin 1998). It has been argued that RS represents a "sharpening" mechanism within the neural population that engage in the processing of the repeated stimulus (Grill-Spector et al. 2006; Wiggs and Martin 1998). Thus, the amount of RS reflects the capacity of neural populations to discriminate different information and can thus be viewed as a novelty detection mechanism and a more efficient coding of the sensory input (Caharel et al. 2009; Grill-Spector et al. 2006; Jenkins et al. 2010; Vizioli et al. 2010). RS has been reported in EEG and fMRI studies across a variety of cognitive tasks (e.g., Gutnisky and Dragoi 2008; Müller et al. 1999; Todorovic and de Lange 2012; Vizioli et al. 2010). Interestingly, RS has recently been observed in cross-cultural studies on the blood oxygenation level-dependent (BOLD) signal with functional magnetic resonance imaging (Goh et al. 2007; Jenkins et al. 2010). Jenkins et al. (2010) found a significantly larger RS to incongruent scenes than to congruent scenes in bilateral occipital cortex for Chinese participants. This observation suggests that EA observers engage more in object processing when it appears in incongruent than in congruent contexts, which also indicates a bias towards global processing in this population. However, the temporal dynamics of this cultural perceptual bias are still largely unexplored.

To clarify this issue, we took full advantage of the conjoint use of Navon stimuli with an EEG adaptation paradigm, in order to map out the temporal dynamics of global/local shape processing in WC and EA observers. EA and WC observers viewed sequences of two Navon figures (an adaptor and a target, see Figure 4.1), while we recorded their scalp EEG signals. Importantly, Navon images were constituted by elementary geometric shapes equally familiar to both groups of observers (and not by Romanic letters, for which Westerners have greater experience). Participants performed an active categorization task requiring the selective detection of (a potential) change occurring either on global or local features on the target image. To control for electrophysiological artifacts generated by saccades, we simultaneously recorded the eye movements and participants were trained to fixate at the center of the screen. Moreover, instead of applying a conventional electrophysiological analysis that would only focus on the target ERPs, we adopted the novel single-trial analysis method developed by Vizioli et al. (2010). Electrophysiological responses elicited by the target shapes were subtracted from those elicited by the adaptor shapes independently at the single-trial level (see methods). To better estimate their temporal sensitivity, we then used a data-driven spatio-temporal analyses carried out independently at all electrodes and all the time-points. Our results showed that EA observers were more efficient at detecting global changes compared to WC observers. This behavioral effect was paired with larger RS responses for global changes as early as 80 ms after stimulus onset, on the attention-sensitive P1 component. These results confirm and refine the cultural perceptual bias for global processing in Easterners, a process that occurs very early and it is rooted into selective attention.

4.2 Methods

Participants

Twelve East Asians (7 females) and 12 Western Caucasians (6 females) took part in the study. All participants were students from the University of Glasgow with normal or corrected-to-normal vision. Participants' ages ranged from 20 to 29 years (mean age 25.7). All the EA participants were from Mainland China, and had no previous experience with a Western country. The maximum duration of residence in the UK for the EA participants upon testing was less than 6 months. The experiment received the approval of the local ethical committee and all participants provided written informed consent.

Stimuli and procedure

Stimuli were hierarchical Navon figures composed by five different shapes: circle, cross, diamond, square, and triangle (Navon, 1977; see Figure 4.1). We employed geometric shape to avoid familiarity differences with alphabet letters between two groups of observers. The local shapes (0.6° × 0.6° of visual degree at a viewing distance of 70 cm) were equally spaced and arranged to create the global shapes (5.8° × 5.8°), resulting in a total number of 25 different stimuli. To minimize the effect of low-level visual adaptation stemming from identical images, the size of the target Navon stimulus was slightly larger than the adaptor (0.72° × 0.72° on local level and 6° × 6° on global level). Stimuli were presented on a Dell P1130 19” CRT monitor with an 800 × 600 pixel gray background, at a refresh rate of 170 Hz.

At the beginning of the experiment, participants sat in a dimly lit, sound-attenuated electrically shielded booth. Each trial started with a fixation cross (0.3°) presented at the center of the screen for 300 ms. The adaptor was presented for 800 ms, followed by an interval duration randomly ranging between 150 to 300 ms. The second shape was then presented for 600 ms. Following the offset of the target stimuli, subjects were required to respond by pressing a key on a standard computer keyboard. A randomized inter-trial interval between 1200-1500 ms preceded the beginning of the following trial.

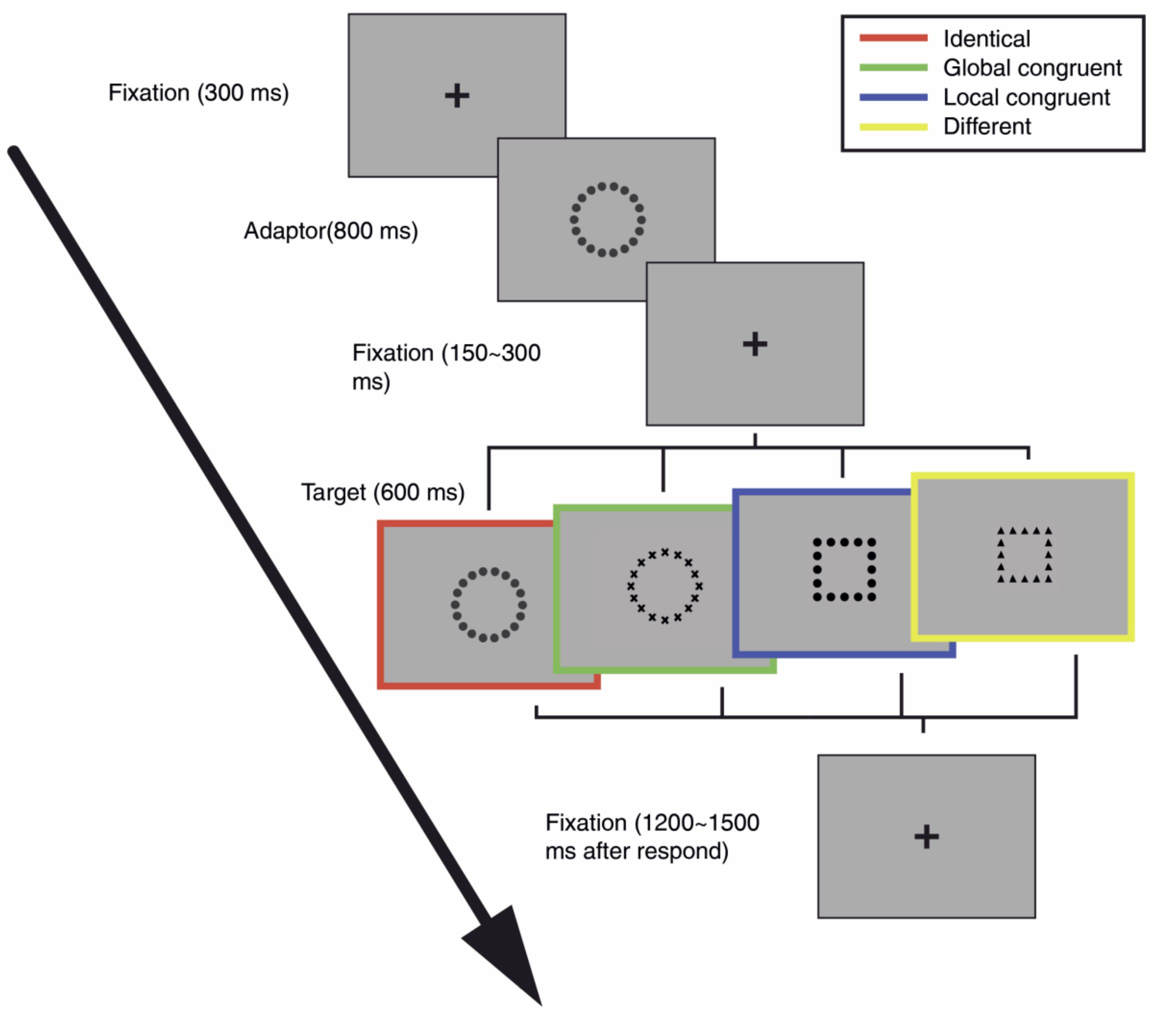

Figure 4.1, Experimental procedure. Different color in the target represents the condition in the current study (as shown in the legend)

We used a forced choice task. During the experiment, participants categorized the feature change between each pair of adaptor and target. There were four conditions: 1) *identical*; 2) *global congruent* condition, where only the local features were changed; 3) *local congruent* condition, where only the global features were changed; 4) *different* - both local and global features were different. Upon the offset of the target, participants assigned the trial to one of the conditions by pressing one of the four pre-assigned buttons, corresponding, respectively to the letter “d”, “f”, “j”, and “k”. An example sheet (similar to Figure 4.1) was provided prior to beginning the experiment to explain the four possible conditions. Participants were instructed to respond as quickly and as accurately as possible. To prevent perceptual and decisional bias, we counterbalanced all 25 stimuli so that all stimuli would appear in the same proportion both as an adaptor and as a target in each condition and the trial sequence was also randomized. Moreover, to minimize the potential EEG artifacts generated by eye movement, we monitored and processed participants' eye movements online for trial validation. Trials containing blink or saccade during stimulus presentation were excluded. We defined a trial as valid if the gaze-drift during the stimulus presentation was less than 1° of visual angle away from the fixation cross. Prior to commencing the experiment, participants performed 20 practice trials to familiarize themselves with the task. The experiment ended when a participant completed 600 valid trials (4 conditions × 150 repetitions). Subjects were given a short break every 100 trials. The whole experiment was programmed in Matlab 2007b, using the Psychophysics Toolbox (PTB-3, Brainard, 1997; Kleiner et al, 2007).

Eye tracking and EEG recording.

Eye movements were recorded by means of Desktop-Mount EyeLink 2K eyetracker (SR Research Ltd., Mississauga, Ont., Canada) with a temporal resolution of 1000 Hz, a spatial resolution of 0.01°of visual angle and an average gaze position error of about 0.25°. Eye movements were recorded monocularly on the dominant eye. The eye movement data were recorded via Matlab (R2006a), using the Psychophysics (PTB-3) and EyeLink Toolbox extensions (Brainard, 1997; Cornelissen et al, 2002). Calibration and validation of eye fixation were conducted before the experiment and repeated whenever necessary during the procedure.

The EEG data was recorded continuously at 1024 Hz from a 128-channel Biosemi Active Two EEG system (Biosemi, Amsterdam, Netherlands). Ag/AgCl electrodes were placed in a nylon cap following the 10-5 system (Oostenveld and Praamstra 2001). Data were band-pass filtered (0.1 and 100 Hz) online. Electrode impedance was kept between ±25 kΩ. The recording reference and ground consisted of two active electrodes (CMS, Common Mode Sense; DRL, Driven Right Leg. For further information see www.biosemi.com). Subjects were asked to minimize blinking, head movement, and other body movement.

Behavioral and EEG analysis

We carried out 2 (*groups of observers*) × 4 (*feature changes*) mixed model ANOVAs independently on the reaction time (RT) and accuracy rate (ACC). The two groups of observers (WC and EA) were the between subjects factor and the four conditions (*identical; global congruent; local congruent;* and *different*) were the within subjects factors. Moreover, to take into account both measurements, inverse efficiency score (IES - Bruyer and Brysbaert 2011; Townsend and Ashby 1978, 1983) was calculated as:

$$IES = RT / ACC$$

Only trials with correct behavioral response were analyzed (93.7% for WC and 95.5% for EA, detailed in Result session). EEG data was preprocessed and analyzed using Matlab and EEGLAB toolbox (Delorme and Makeig 2004). The raw signal was referenced off-line to an average reference, and low-passed filtered at 40 Hz. Noisy electrodes were excluded, and interpolated using a spline interpolation algorithm implemented in EEGLAB on a subject-by-subject basis. EEG data were epoched from -100 ms to 500 ms relative to stimulus onset, separately for adaptor and target, independently per condition. Baseline was defined as 100 ms prior to, until stimulus onset. Baseline correction was applied by removing the average baseline amplitude from every time point independently for each epoch. To fully exploit the paired nature of the adaptation design, trials were only accepted if both signals elicited by adaptor and target stimuli were below the rejection threshold. Single-trial repetition suppression (stRS) was then calculated for the accepted trials only, by subtracting the target shape epoch from the adaptor epoch. For more details about the procedure, see Vizioli et al. (2010).

We carried out the same 2 (*group of observers*) × 4 (*feature change*) mixed model ANOVAs independently at all electrodes and all time-points on the stRS amplitude. To correct for multiple comparisons, we used robust statistics, including bootstrap (Wilcox 2005) and a multivariate clustering technique (Maris and Oostenveld 2007; Vizioli et al. 2010). Within each group, we first centered each stRS trial on the mean amplitude so that each condition had a mean of zero. We then used bootstrap, sampling with replacement the subjects, to derive an estimate of the sampling distribution under the null hypothesis of no difference across the conditions' means. We carried out the mixed model ANOVAs (as described above) independently at all electrodes and time-points on the centered bootstrapped stRS. The significant F values ($P < 0.05$) were then grouped in spatiotemporal clusters (Maris and Oostenveld 2007; Vizioli et al. 2010). We computed the sum of F values in every cluster and selected the maximum cluster sum. After repeating the same procedure 500 times, we sorted all the cluster sums according to their values and selected the

95th percentile as the cluster threshold. The original ANOVA clusters F-value sums were then compared with the bootstrap cluster threshold. If an observed cluster sum was equal to or larger than the threshold sum obtained under H0, all of the time-points and the electrodes contained in that cluster were considered significant (Vizioli et al. 2010).

4.3 Results

Behavioural results

The behavioral results are summarized in Figure 4.2. The 2 x 4 ANOVAs carried out on RT, ACC and IES showed significant main effects of *feature change* for RT [F (3,66) = 52.07, $p < .05$], ACC [F (3,66) = 30.17, $p < .05$], and IES [F (3,66) = 49.49, $p < .05$]. Post hoc paired-sample t-tests indicated that both *groups of observers* responded faster and more accurately to the *identical* condition compared to the others. No main effect of *groups of observers* was observed for all three measurements [RT: F (1,22) = 0.96; ACC: F (1,22) = 1.66; IES: F (1,22) = 1.52. All $p > .05$].

Importantly, we observed a significant interaction of *group of observers (2)* x *feature change (4)* for the IES [F (3, 66) = 3.59, $p < .05$]. To clarify this result, we performed post hoc paired-sample t-tests on the IES values between the *local* and *global congruent* conditions independently for each group of observers. This analysis revealed that WC observers identified *local congruent* items (M = 673 ms, SD = 293) significantly slower than the *global congruent* ones [M = 551 ms, SD = 229, t (11) = 2.79, $p < .05$]. No differences were reported between *global* and *local congruent* conditions for EA observers [t (11) = 1.41, $p > .05$].

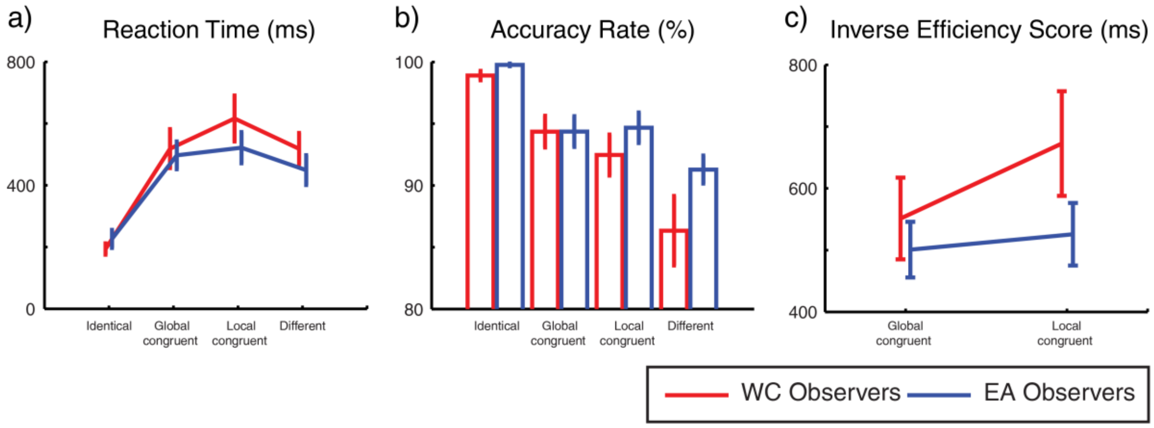

Figure 4.2, Results of reaction time (a), accuracy rate (b), and inverse efficiency score (c). Only global congruent and local congruent conditions are shown for the inverse efficiency score (c). Error bars show standard errors from the means

Single-trial RS results

The minimum number of accepted trials across all subjects and conditions was 100. Figure 4.3 shows the adaptor ERP, target ERP, and stRS for the electrode where the F values for the *groups of observers* x *feature change* interaction was maximal (i.e. P4).

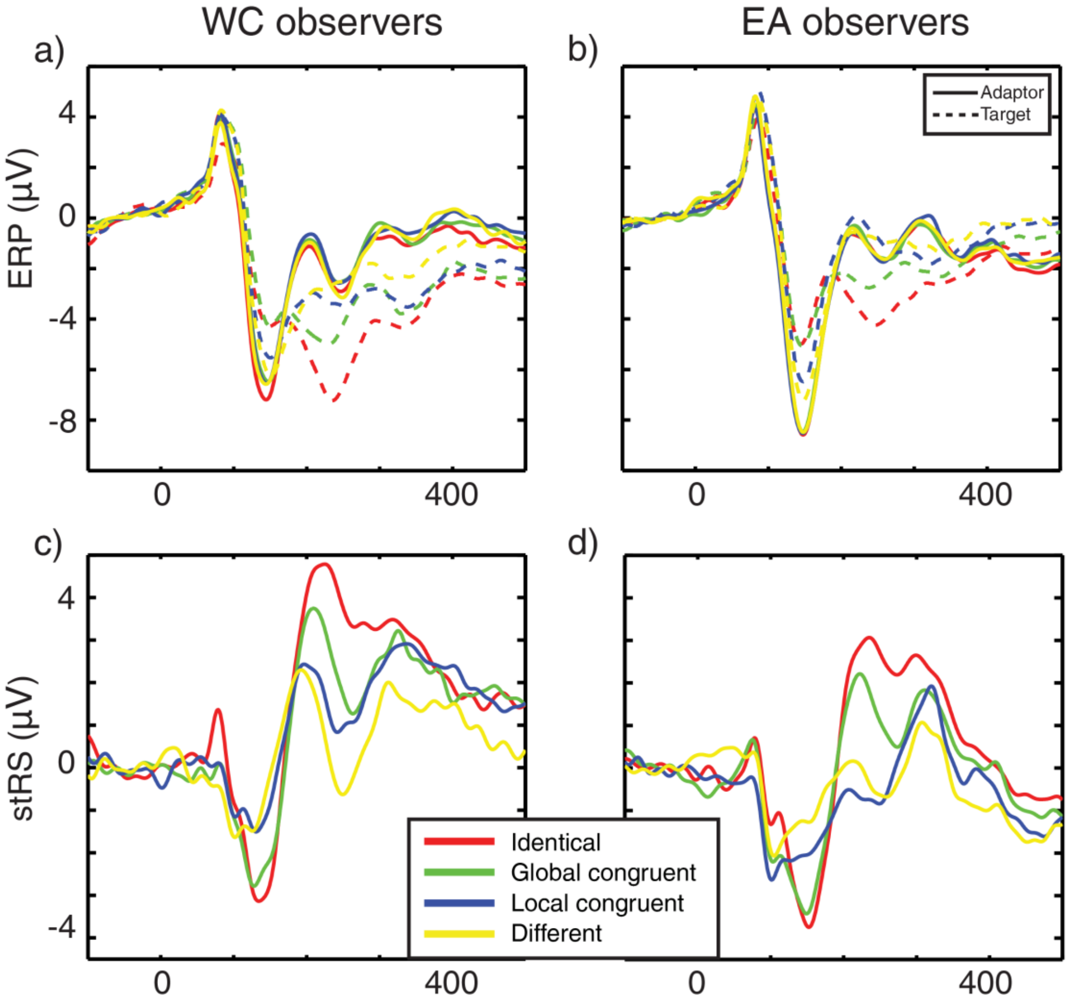

Figure 4.3, ERP and stRS for P4. a) and b) depicts the mean ERPs elicited by the adaptor (solid line) and the target faces (dashed line) for the four conditions (identical, red line; global congruent, green line; local congruent, blue line; different, yellow line) for WC (a) and EA (b) observers. stRS responses are shown in (c) for WC and (b) EA

After multiple comparisons correction, the Mix-model ANOVA revealed a significant interaction (*groups of observers* × *feature change*) at two spatial-temporal clusters (Figure 4.4a). The first cluster was located at right occipito–parietal electrodes

(Figure 4.4b). Its time-window was within the latency of the P1 component, which ranged from 60 to 110 ms. The F-value of the first cluster reached its maximum at 88 ms at electrode P4 [minimum $F (3, 66) = 2.24$; maximum $F (3, 66) = 8.32$, $p < .05$]. This was the same electrode where P1 component reached its maximum amplitude. Post hoc paired-sample t-tests showed that *global congruent* trials elicited significantly larger stRS responses compared to *local congruent* condition in EA observers [$t (11) = 3.26$, $p < .05$]. No significant difference between *global* and *local congruent* conditions were observed for WC observers [$t (11) = 0.39$, $p > .05$. See Figure 4.4e].

The second significant spatial-temporal cluster occurred within the time-window ranging from 200 to 350 ms (i.e. the posterior N2 component) and was spatially located around the anterior parietal electrodes (Figure 4.4b). F-value topography maps revealed 3 local maxima with different spatial distributions (See Figure 4.4c & d). The first occurred at 236 ms at electrode CP6 with a right-lateralized topography [$F (3, 66) = 8.42$, $p < .05$, Figure 4.4c]. Post hoc paired-sample t-tests indicated larger stRS responses to *local congruent* compared to *global congruent* conditions for EAs [$t (11) = 2.4$, $p < .05$] but not WCs [$t (11) = .18$, $p > .05$, Figure 4.4f]. The second maximum occurred at 273 ms over center-parietal electrodes [C2, $F (3, 66) = 10.01$, $p < .05$, Figure 4.4d]. Post hoc paired-sample t-tests indicated that WCs displayed larger stRS responses to *global congruent* compared to *local congruent* conditions [$t (11) = 2.24$, $p < .05$]. No significant differences were observed for EAs [$t (11) = .21$, $p > .05$, Figure 4.4g]. The third maximum was observed at 312 ms at electrode C5 [$F (3, 66) = 9.29$, $p < .05$]. Post hoc paired-sample t-tests showed significantly larger stRS responses to *local congruent* compared to *global congruent* conditions for WCs [$t (11) = 4.30$, $p < .05$]. No significant differences were observed for EAs participants [$t (11) = 2.145$, $p > .05$].

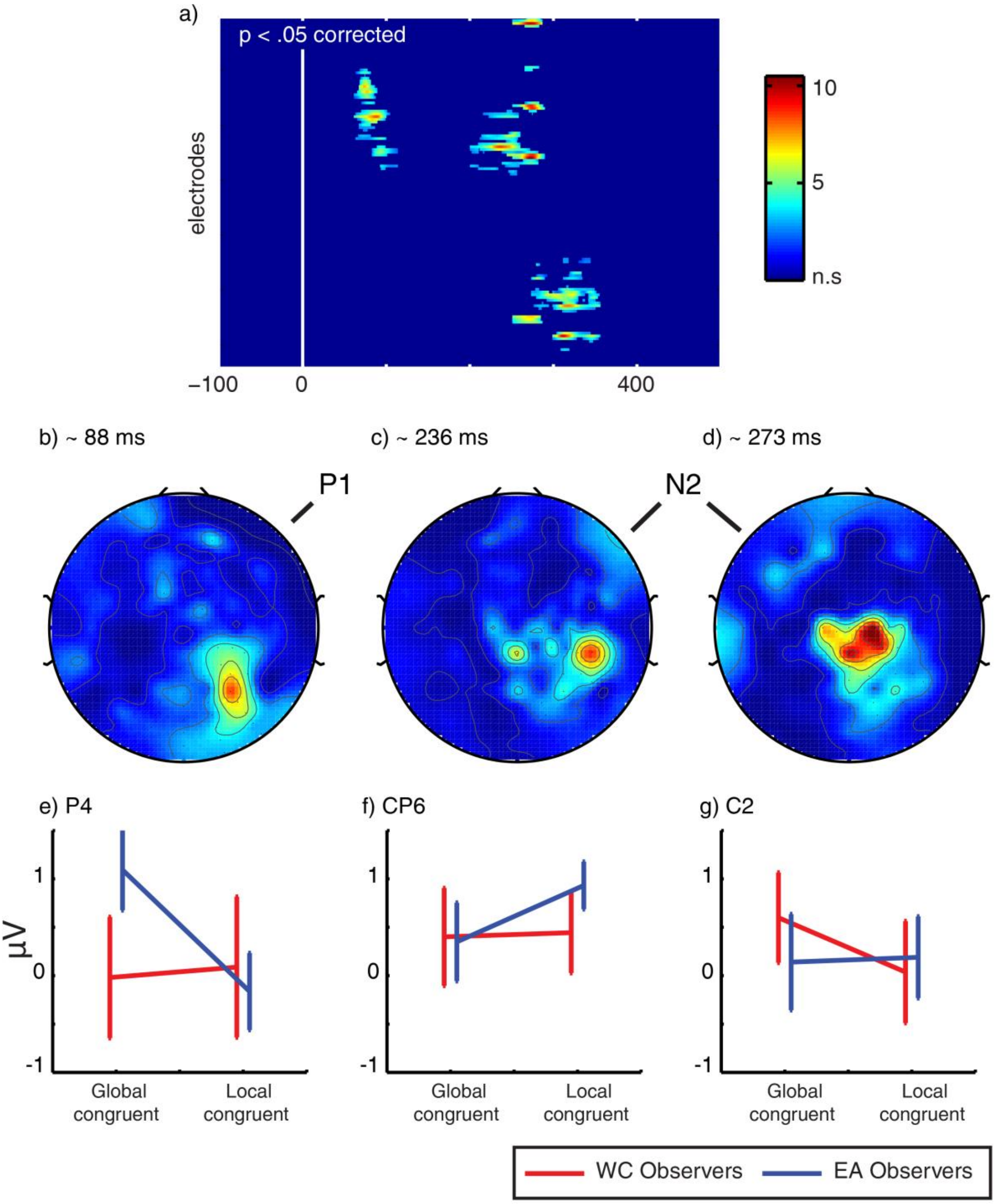

Figure 4.4, Significant interaction of spatial-temporal ANOVAs. (a) Significant F values of the groups of observers × feature change interaction on the stRS amplitude. The x-axis depicts the time points of the stRS epoch, while the y-axis indicates the 128 electrodes. The electrode order is unrelated to their spatial topographical positions. (b), (c), & (d) portrays the F-value topography maps at the local peaks of the P1 and N2 spatial-temporal clusters. For illustration purpose, here the first two local peaks of the N2 cluster are shown. (b) represents the F-value topography of the P1 spatial-temporal cluster at 88 ms (latency of the peak F-value),which was maximal at electrode P4. (c) & (d) show F-value topographies of the N2 spatial-temporal cluster at two local F-value peaks (236 ms and 273 ms). The peak electrodes were CP6 and C2,

respectively. (e), (f), & (g) illustrates the mean stRS responses of global congruent and local congruent conditions for WC and EA observers at each F-value peak latency at the respective electrodes. For display purposes, stRS on the negative component was multiplied by -1. Thus, more positive values indicate larger repetition suppression. Error bars show standard errors from the means.

4.4 Discussion

The present study aimed to address *whether* and *when* cultural perceptual tunings to global/local information are driven by attention. We directly tested this hypothesis on Western Caucasian (WC) and East Asian (EA) observers while recording their scalp electrophysiological signals during the visual categorization of hierarchical shapes differing in their global/local properties. We used an adaptation paradigm, as well as a single-trial method coupled with robust data-driven analyses on all the electrodes and time points. The behavioral results showed that EA observers display a global advantage by processing more effectively visual changes on this visual property compared to WC observers. More importantly, our electrophysiological data showed that global/local feature repetition modulates the P1 and N2 ERP components as a function of culture. Specifically East Asian observers showed greater sensitivity to *global* congruency on this component compared to WC observers. These observations confirm the existence and refine the knowledge on the cultural attentional biases in visual information sampling, which are consistent with previous observations (Kitayama et al. 2003; McKone et al. 2010). Importantly, this early neurophysiological signature of cultural diversity in Easterners cannot be accounted by the inherent nature of the stimuli and/or task, as it was not present in Western Caucasian observers. Westerners showed sensitivity to hierarchical Navon shapes discrimination at later stages.

Attention modulation on the P1 component

We reported an interaction between the culture of the observers and the neural sensitivity to global/local information coding at early stages of visual information processing. Firstly, only EA participants showed larger stRS responses to global compared to local feature repetition, as early as 80 ms after stimulus onset; the time window of the P1 ERP component. The P1 is a positive deflection peaking between 70 and 120 ms at central occipital electrodes, which has been consistently related to attention (Luck, Woodman, & Vogel, 2000). The P1 amplitude modulations observed in EA observers suggest that the global precedence in this population is modulated by attention. Importantly, there is a growing body of evidence positing that larger RS responses reflect greater neural coding efficiency (Caharel et al. 2009; Grill-Spector et al. 2006; Vizioli et al. 2010). Although the precise neural mechanisms of RS are still debated, numerous models have been proposed to account for the reduction in neural activity following stimulus repetition (Grill-Spector et al. 2006; Schacter et al. 2007). The most prominent account – the sharpening model – holds that the neuronal representations of a stimulus become less redundant and sparser with repetition (Grill-Spector et al. 2006). Under the same model, RS can also be considered as a neural novelty detection mechanism (Vizioli et al. 2010). Therefore, the larger amount of RS to global features for EA observers can result from a more efficient neural coding of global information at this stage, which is reflected in the sharpening of global feature representations as a function of attention. Moreover, the absence of significant differences in the amount of stRS between global and local feature repetition in Westerners suggests that, at least at early neural stages of processing, there is no preferential tuning to either global or local information coding in this population.

In line with our findings, the sensitivity to global/local selective attention on the posterior P1 component has previously been reported in a number of studies (Han et al. 1997, 1999; Han et al. 2000; Lin et al. 2008). For example, the priming of interdependent self-construal, which is closely related to global perceptual bias (Kühnen and Oyserman 2002; Lin and Han 2009), enlarged the P1 amplitude to global compared to local features in Chinese participants (Lin et al. 2008). Similarly, Han et al. (1997, 1999 & 2000) showed that selective attention to global or local feature modified the P1 amplitude in EA observers. The data reported here are in line with previous studies, reinforcing the view of an early sensitivity to global information coding on the P1 component in Easterners only. In contrast, WC observers did not show sensitivity to their preferred (i.e., local) features in this early component. It is worth to point out that in the current task observers were forced to attend equally information at both the global and the local levels, since they could not predict the nature of the potential change in target shape. Therefore, in this task global processing might be more dominant than local processing. Thus, the absence of sensitivity in Westerers on the P1 component could be accounted by the ineherent, general, slower processing of local compared to global features in visual information processing.

Moreover, EA observers showed a behavioral advantage on the global task compared to WC observers. This advantage is likely to arise from their early attentional bias towards global information. In fact, we found that WC observers were less efficient at detecting global than local feature changes, while EA observers performed equally well on both conditions. The behavioral disadvantage of WC observers in the global task seems to stem instead from differences in visual saliency between global and local features. Specifically, the visual processing of global features precedes the analysis of local information (Navon 1977). This global precedence effect would conflict with local information, thus inhibiting responses to the detection of local features (Han et al. 2001; Miller and Navon 2002; Navon 1977). For example, participants are slower at identifying local targets in the presence of interference from a global shape, even when this information is irrelevant (Miller and Navon 2002). The change of global features is disruptive for WC observers when they are required to detect changes in local information (i.e. distinguish between *local congruent* and *different* condition). As comparison, EA observers benefit from a top-down attention control to global features, thus limiting the disturbance from the visual salience induced by global feature changes (e.g., the interface hypothesis, McMains and Kastner 2011).

Cognitive control effect on the N2 component

We also observed an interaction between the culture of observers and global/local information tuning over the central-anterior-parietal electrode site at around 200 - 350 ms. A fine-grained adaptation pattern revealed distinctive temporal dynamics of global/local processing between Westerners and Easterners. Specifically, EA observers showed larger stRS responses to local compared to global feature repetitions over the right anterior-parietal electrodes at 240 ms. WC observers instead displayed first larger stRS responses to global compared to local feature at 270 ms, to then show a reverse pattern at 320 ms. This modulation occurs in the time window of the N2 component, which has a distinct topography (see. Fig. 4c & d) and has been related to cognitive control (see Folstein and Van Petten 2008 as a review). Cognitive control is partly defined as being a strategy regulation process during response to novelty or (mis)match detection (Nieuwenhuis et al. 2003; Yeung et al. 2004; Zhang et al. 2003). For example, slower behavioral responses resulting from larger demands in cognitive control are correlated with larger N2 amplitudes and delayed peak latencies (Gehring et al. 1992; Nieuwenhuis et al. 2003). Moreover, inhibition of behavioral response also elicits larger N2 amplitudes, especially when stimuli share similar visual features (Folstein and Van Petten 2008). Here, regardless of their cultural background, all the observers engaged a larger amount of neural resources during the processing of the cultural non-preferred features to overcome the interference from the cultural preferred features. Therefore, the fewer amount of stRS responses elicited by *local* feature repetition in WC observers and the fewer amount of stRS responses for *global* feature repetition in EA observers on the N2 component might reflect a more demanding engagement of cognitive resources devoted to performing (mis)match detection for the non-preferred feature repetition. More specifically, these resources might be related to the inhibition of the culturally-preferred bias in visual information sampling (i.e., consistent local feature for WCs and consistent global feature for EAs).

General discussion

The conjoint use of EEG and Navon stimuli has been widely used to investigate the temporal dynamics of attention modulations in global/local shape processing (Han et al. 1997, 1999; Han et al. 2000; Heinze et al. 1998; Heinze and Münte 1993; Malinowski et al. 2002). Surprisingly, while this approach has been extensively used in a wide range of studies on WC observers and EA observers separately, no previous study had yet *directly* compared these two groups of observers. Here, we overcame this limitation by testing both groups of observers. As discussed above, our results precisely mapped out and confirmed that the temporal dynamics of global/local processing is indeed different between Easterners and Westerners. More precisely, EA observers show a distinct early sensitivity between global and local feature coding compared to WC observers. Such difference in temporal dynamics of visual shape processing is driven by an initial attentional selectivity and tuning between these two groups of observers from different cultures: a global selective-attention in Easterners and a local-selective attention in Westerners (McKone et al. 2010).

Previous studies on global/local visual shape categorization have suggested that the processing of hierarchical visual stimuli is lateralized in the brain. A left hemisphere advantage has been reported for local processing at the encoding stage, and a right hemisphere advantage for global processing (e.g., Folstein and Van Petten 2008; Han et al. 2002; Lamb et al. 1990). Unfortunately, it is difficult to interpret our results in terms of hemispheric asymmetries. Although we found an interaction, for which the effect is lateralized in both spatial-temporal clusters (i.e., on the right scalp electrode locations in P1 and on both side of scalp electrode locations in N2), we did not modulate the visual field presentation nor counterbalanced the response keys across participants. The interpretation of our findings without these controls could be potentially misleading, and further research is required to elucidate this issue.

Conclusion

The present study demonstrated that the temporal dynamics of global-local feature coding is shaped by culture. Our data show an early attentional bias in Easterners for global visual properties during an active matching task of Navon hierarchical stimuli. East Asian observers showed strong EEG repetition suppression responses to global compared to local features on the attention-sensitive P1 component. This global precedence effect in Easterners was paired with a more efficient processing of global feature changes at later stages. Western Caucasian observers displayed instead the expected differential electrophysiological responses between global and local information processing, but in later electrophysiological stages (i.e. N2 component). These findings support the view that cultural perceptual biases in visual perception are driven by selective attention. Importantly, they also provide cultural neural signatures and their temporal dynamics for global/local feature processing. Overall, these distinct neural markers could represent the entry level of the more apparent and striking differences observed at the behavioral level across observers from the Western and Eastern cultures.

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5 General Discussion

The main purpose of this thesis was to explore the temporal dynamic of culture modulation effect on visual cognition. In particular, the current thesis focused on two important questions: when and how culture shapes our visual experiences. To directly investigate the temporal modulation effect of culture, here I exploited the advantages conferred by EEG (specifically ERPs) and further developed a novel fixational eye movement paradigm. The high temporal resolution provided by these two methods, combined with data-driven analytical approach, is ideal to reveal the time course of culture influence. The first two studies employed human faces as stimuli, to investigate the information processing on different facial locations as a function of cultural specific eye movement strategy. The third study made use of hierarchical stimulus to access the attention modulation of global/local processing in WCs and EAs. As shown in all three experiments, early differences in visual processing between WCs and EAs are mostly driven by low-spatial frequency information or global strategy, whereas detail processing of high-spatial frequency information largely reflects later stages. In this section, I will firstly elaborate the cultural differences in face recognition (i.e. study 1 and 2) and move on to the general global-local bias. I will then discuss the implications of the current results in various domains. Finally, I will review evidences from all three studies to interpret how culture modulates human perception based on different competitive theories.

Overall, the results reported here show perceptual and cognitive divergences between WCs and EAs. The first two experiments demonstrated that the visual information perceive on face preferred viewing location is tuned by culture. Similar to previous findings, free-viewing eye movement results showed differences in fixation pattern between WC and EA observers in both studies. Westerners preferentially gaze at the eyes and mouth, whereas Easterners fixate more on the center of the face (Blais et al. 2008; Caldara et al. 2010; Kelly et al. 2010; Kita et al. 2010; Miellet et al. 2013; Rodger et al. 2010). Importantly, while maintaining observers' gaze at the upper part of the face (i.e., eyes area) optimizes their face identification performance in both groups, gaze stabilization on their preferred viewing location is behaviourally beneficial for WCs only. The first experiment demonstrated that culture shapes the high-spatial frequency information sampling on preferred facial fixation position.

Higher microsaccade onset rate was shown on the preferred fixation location around 450 ms, which allows better visibility of fine-spatial details. Importantly, WCs exploit the re-sharpen of high-spatial frequency information to improve their behavioural performance, whereas EA observers do not utilize such visual gain. Accordingly, the second experiment investigated the conjoint effect of culture and face viewing position on electroencephalography signal. By regressing between fixation preference of a selective face location with the ERP elicited by force fixation at that location, Study 2 revealed that gazing at the preferred viewing position evoke universal and culturally specific electrophysiological response. Specifically, an early regression pattern was shown on the central-occipital electrode sites for EAs only: larger ERP amplitude is observed at the more preferred viewing location around 130 ms. Such an effect corresponda to the larger attention span of EAs during fixation (Miellet et al. 2013). Furthermore, ERP activity around 350 ms at bilateral occipito-temporal electrode sites increased on preferred viewing position in both groups of observers, suggesting a general cognitive function of PVLs. Taken together, the first two experiments indicate that culture modulates the perceptual and cognitive function of facial preferred viewing location. Human beings actively attend to and sample diverse facial information from their preferred eye movement strategy. The last study examined whether the early perception tuning of global-local bias also expands to culture-unrelated stimulus. Indeed, correspond with their global processing advantage, larger repetition suppression is observed following global than local feature repetition in the EA observers at the P1 component. Notably, repetition suppression reflects coding efficiency of the selective representation (Grill-Spector et al. 2006). A larger adaptation effect to global feature confirmed the attention selectivity to global information for EAs (Nisbett et al. 2001). In summary, these results strongly suggest that culture perceptual bias is driven by the selective attention during information sampling, which further influence the cognition process at the later stage. Westerners attend to the information in the fine spatial details and perceive it with a local strategy, whereas Easterners prefer to employ a global strategy to sample low-spatial frequency visual information. Such perceptual tuning differences result in modulation at both early and late time-course as demonstrated in the current thesis. Moreover, both information sampling strategies are potentially advantageous, depending on the available information and the nature of the task.

5.1 Implications

Implications for cross-culture research.

To the best of my knowledge, the results provided in the current thesis are the first empirical evidence of the temporal divergence in visual processing between WCs and EAs. By tracking the time course of perceptual difference between two groups of observers, these results taken together reveal that culture diversity in the cognitive process appears at early processing stage (~80 ms). Specifically, EA observers showed stronger electrophysiological response to their preferred information in the perceptual stage (i.e., larger ERP at around 130 ms to face information sampling from PVL in Study 1 and greater adaptation effect at around 80 ms to global feature in Study 3), whereas WCs did not share similar sensitivities. On the other hand, modulation between experiment conditions related to high-spatial frequency information is revealed in WC observers only at a later stage. For example, better visibility of fine-spatial details produced by microsaccade on their PVLs benefit WCs but not EAs.

The observation of such temporal signature of culture is in line with the different perceptual profile of local and global information. As a result of the physiological property of the human visual system, global features are closely related to fast, categorical process. On the other hand, fine-grained cognitive processing mostly relied on details in local elements (Han et al. 2001; Miller and Navon 2002; Navon 1977). With a global perceptual tuning, EAs show categorical differences between global and local information earlier than WCs. Meanwhile, information from both global and local features is essentially crucial to accomplish complex cognition tasks. Thus, universal patterns in the late time-course revealed in the current experiments might represent that the detail processing of visual information, especially that contains in high-spatial frequency.

These observations confirm the attention bias between WCs and EAs purposed by Nisbett et al. (2001). According to the analytic-holistic cognitive style framework, Western Caucasians perceive the world locally, whereas East Asians see the world in a more global way. People with an analytical cognitive style, as suggested by Nisbett, attend more to the focal objects and their visual properties. Instead, the holistic cognitive style biases East Asians toward the information in the context and the relationships among objects. Here by using both social and non-social stimuli, I showed that such cognitive bias might closely relate to the perceptual tuning to different spatial-frequency spectrum. Indeed, by preferably attend to the low-spatial frequency information, EA observers showed early sensitivity to global elements, whereas the cognitive advantage of high-spatial frequency information is revealed for WCs in later stage, driven by their bias to local features.

In summary, the current work provides an important contribution in understanding how culture influences the temporal dynamics of information processing. As proposed by Nisbett et al (2001), culture shapes observer's preference to local or global information. Here, my results showed that the interaction between the culture of the observer and the type of information operates on different time course during visual processing. Depending on the nature of the task, visual information essential to the task is different. Whether culture diversity appears or not, and when such diversity is expected to emerge, is designated by observers' initial bias to the particular range of spatial frequency information and the type of task.

Implications for face perception mechanism.

The human visual system is markedly tuned to face stimulus (Solla et al. 2000). Brief presentation or fixation of the face is sufficient for various tasks including categorization and identification (Hsiao and Cottrell 2008; Peterson and Eckstein 2012). For example, by momentarily fixated just below the eyes, observers could obtain enough diagnostic information to optimize face recognition (Peterson and Eckstein 2012, 2013). However, human observers usually follow various eye movement patterns with alternating saccadic transitions among eyes, mouth and nose. Notably, the eye movement pattern during face free viewing is shaped by culture (Blais et al. 2008; Caldara et al. 2010; Kelly et al. 2010; Kita et al. 2010; Miellet et al. 2013; Rodger et al. 2010). WCs follow a "triangle" pattern containing eyes and mouth, whereas EAs preferably fixate on the center of the face (Caldara et al. 2010). Different explanations have been proposed regarding the perceptual function of preferred eye movement pattern (Caldara et al. 2010; Miellet et al. 2013; Peterson and Eckstein 2012). Previous studies from our lab by the means of gaze-contingent paradigm and information reconstruction technique showed that different spatial frequencies of visual information are sampled during fixation strategies depending on the observer's initial perceptual tuning (Caldara et al. 2010; Miellet et al. 2011;

Miellet et al. 2013). Alternative hypothesis suggested that the vast majority of fixations during free viewing do not contribute to perceptual decision (Peterson and Eckstein 2012). It proposes that after gathering and processing sufficient information during the first few fixations, observers revert to a default mode of eye movement patterns that reflect their standard social behaviour (Peterson and Eckstein 2012). Here, I provided the first empirical evidences of the functional role of preferred viewing location in face recognition. Microsaccade result confirmed that WC observers rely on high-spatial frequency information from their preferred viewing location. Moreover, direct relationship between fixation preference and P3 amplitude in both groups of observers suggests a physiological function of the preferred viewing location. Such "re-activation" of the occipital–temporal face network indicates that the observer's mental face representation might closely relate to his eye movement pattern. The preferred viewing location during face free viewing is not only a reflection of social behaviour, but also has important perceptual and cognitive value.

Implications for methodology

The present thesis introduces novel approaches in both experiment paradigms and data analysis. I innovated an original technique to apply microsaccades as a measurement for the perception of high-spatial frequency visual information. Recent evidences have shown that the perceptual outcome of microsaccade is similar regardless of the potential different origins. Notably, it enhanced visibility during fixation (Martinez-Conde et al. 2006), counteracted visual fading both foveally and peripherally (McCamy et al. 2012), and re-sharpen fine-spatial details for feature extraction (Donner and Hemilä 2007; Kuang et al. 2012). Here by investigating the temporal dynamic of microsaccade onset, I showed that WC observers make use of high-spatial frequency information from their preferred viewing position. Moreover, I also introduced a novel method to analyse the temporal dynamic of microsaccade. Transient oculomotor events such as microsaccade are difficult to examine in the same way as continuous signals (Otero-Millan et al. 2012). Previous analysis usually conducted in a predefined time-window on the smoothed time course (e.g., Engbert and Kliegl 2003). Instead, I employed a data-driven method to objectively sample microsaccades as they occurred in different time range. Combined with temporal clustering as multiple comparison correction, we could therefore explore the essential time window of functional microsaccades.

Here I also presented a novel method to combine free-viewing eye movement and electrophysiological measures. Regression analysis is introduced to combine temporally sensitive and spatially sensitive methods. I measured observers' fixation patterns in a separate free viewing face learning session and directly link with the electrophysiological signals. The individual preferences to different face features are evaluated according to the fixation map as an indicator to predict the signal change in EEG recording. Data-driven analysis, without prior assumption of components or time-windows, exploits the full advantage of these high temporal resolution measurements.

5.2 Future Directions

In the substantial history of cross-cultural research, different theories have been proposed to account for the mechanism of culture modification on perception. Hypothesis suggested various intermediate factors that might contribute to the cultural differences in information processing. Such factors include historical influence in philosophy (Nisbett et al. 2001), social organization represents as individualistic or collectivist (Markus and Kitayama 1991), immediate psychological factors such as self-construal (Han et al. 2013) or sense of personal control (Zhou et al. 2012), and clutter of the visual environment (Caparos et al. 2012; Miyamoto et al. 2006). While these hypothesized factors are all partially supported by existing evidences, the exact contribution and the possible interaction among them remains un-clarified. Although the current thesis did not directly test any of these competitive theories, the results observed here might be best explained by the visual clutter hypothesis. Especially, the perceptual tuning to low-spatial frequency information might be more beneficial in a more cluttered visual environment (Itti and Koch 2001; Oliva and Torralba 2006). Indeed, the relationship between visual environment and perceptual tuning has previously been reported. For example, Miyamoto et al (2006) has shown that the scenes from an East Asian country (i.e., Japan) consist of more objects and are more complex than the environments from a Western culture (i.e., America). Moreover, it has been shown that exposure to complex environmental settings influences one's attention to a global bias (Caparos et al. 2012; Miyamoto et al. 2006). Future studies should clarify the potential causal relation between cluttering of the environment and the cultural perception bias. For example, it is possible to quantify the physical properties of the daily visual stimulus for each individual as predictors to correlate with his perceptual bias to visual spatial-frequency span.

Previous results suggested culture differences are relative matters of emphasis rather than absolute differences of capability (Caldara et al. 2010; Miellet et al. 2010; Zhou et al. 2012). Moreover, observers flexibly engage into both types of information sampling strategy, according to their cultural background, individual emphasis, and available information. By identifying the initial information preference within each participant, future studies might be able to fully account for the influence of culture in fundamental vision experiment. Such an idea of reducing culture modification effect to individual differences is worth further investigation (McCrae 2000).

Another important aspect yet somehow missing in cultural studies is how different culture preferences or biases are developed, especially the “mental development milestones”. While results already shown different development pattern in the acquisition of cultural values and social roles, how culture shapes the sensorimotor biases in attention or perception is remain to be clarified. Noticeably, the early visual experience with specific types of stimuli might sculpt the visual recognition and the underlying system (for an example in face perception, see Pascalis et al 2002; 2005). Thus, it would be stimulating to parametrically compare different age groups of observer between different cultural populations. For example, whether local versus global bias is displayed from birth? If not, when and how such perceptual bias is developed in infants? Similarly, do people with East Asia heritage who grown up in the West culture still exhibited an EA-like cognition bias, or vice versa? Our lab is currently testing a specific cultural group in Switzerland. They are Koreans adopted by Swiss family from birth. By comparing this population with the “typical” WC and EA observers in various perception and cognition tasks, we hope to be able to answer some of these questions in the near future.

Overall, my findings in the present thesis provide a new dimension in exploring cultural differences and may potentially stimulate new cross-cultural research in other domains.

5.3 Final Remarks

Human visual experience is culture-specific. The aim of this thesis was to explore the temporal dynamic of cultural modulation on human vision perception. I applied high temporal resolution measurements and various visual stimuli to evaluate perceptual differences between two groups of observers: Western Caucasian and East Asians. As demonstrated in three experiments, cultural diversity appears in the early attention-perceptual stage as well as the late, in-depth cognitive stage. Cultural differences in visual tasks are produced by the joint effect of initial information tuning shaped by culture, and the specific visual information essential for the task.

6 References

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