Analyzing Pedestrians' Perceptions of Security in Urban Streets: the effects of cognition and environment on EEG pattern

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The walkability is a significant indicator of livability of urban cities, which is determined by various factors of street conditions. The security of streets has direct impact on pedestrians' walking experience and relates to incidence of actual crimes or aggressive behaviors against pedestrians. In order to improve the security level of urban streets and build a comfortable and safe walking environment for citizens, on one hand, it should be figured out what the influential factors of occurrence of security issues are, and on the other hand, it's also essential to clarify that how pedestrians' perception of security is influenced. People's perception is identified to be influenced by both psychological cognition and external environment, therefore the cognition of fear of security issues and environmental features of urban streets should be involved in analysis. This research aims to clarify the effects of cognition and environment on pedestrians' perception of security, by investigating participant's cognition of fear of crimes and self-defense and using the technology of electroencephalogram (EEG) to measure the level of psycho-physiological reaction of pedestrians in real-time walking. The correlations between participants' emotional feelings and environmental features was analyzed.

Key Words : *Walking, Pedestrian, Security, EEG, Environment*

1. INTRODUCTION

Building a walkable city has become one of the development goals of most countries in the world in the new era, in order to improve the livability of cities and achieve sustainable development. To measure the walkability of urban space, several efforts have been made in previous researches to develop new concepts or approaches to capture and evaluate the environmental performance in terms of providing a comfortable and safe space for pedestrians, such like Walkability Index and Walk Score®.

In terms of walking safety, in addition to the threat caused by traffic accidents, there are also potential dangers caused by street security issues (sexual harassment, bag snatch, indecency, etc.). Although most pedestrians have no experience of encountering street crimes, the fear of crimes generally exist in their minds and have negative impact on their walking behaviors. In different countries and regions, several previous studies have showed that an increase of people's fear of crimes is associated with a decrease in outdoor walking (Foster et al., 2014; Roman and Chalfin, 2008). Situation is similar in Japan. In recent years, though public security situation has improved in many districts of Japan, a considerable amount of victims still suffer from street crimes each year. According to the results of 5th Questionnaire on Unease in Social Life (2014), more than half of answers feel unease and fearful about crimes when walking in public streets (**Figure 1**), especially the females, who usually play a role of vulnerable population in terms of personal security issues in a gendered society (Stanko, 1995; Sacco, 1990; Carl, 1998).

For pedestrians, not only the actual security of walking spaces is important, their perception of security also have significant impact on their experience of walking and even subjective wellbeing (Shanna, et al., 2021) and neighborhood cohesion (Taylor, 1985). Besides, fear of crimes may cause psychological distress, which is harmful to pedestrians' mental and physical health (Ross, 1993). In order to optimize the walking environment in urban planning, reducing the fear of pedestrians should be placed on the same important position as solving security issues in public walking spaces, therefore, it is of great significance to clarify how pedestrians' perceived security is affected before making any suggestions for environmental improvement.

The perceived security can be attributable to the both environmental features and subjective cognition. The built environment of walking spaces directly interacts with pedestrians, acting on their auditory, visual and other senses. Different architecture patterns, lighting conditions or street width tends to make pedestrians perceive different level of security. Meanwhile the subjective cognition of personal security and self-defense would also determine people's attention of perceived potential danger and sensitivity of perception. To analyze pedestrians' perception of security in real urban walking spaces, both external and internal factors should be involved to reduce bias and avoid taking a part for the whole.

The ideas of measuring peoples' emotional feelings of urban environment started developing since 1960s, the most famous original concept was "Mental Mapping" proposed by Kevin Lynch (Lynch, 1965). From that on, various approaches of matching psychological data with geographical environmental data have been developed to find out the impacts of environment on subjective feelings, however, in most researches the methods of capturing psychological data were limited to traditional ways, like questionnaire survey or interview. These methods have the merits of easy operation, but they are often biased because they are subjectively reported data. With the technical development, later the technology of virtual-reality was used in some laboratorial situations to simulate various urban environment, and the psycho-physiological data of participants was analyzed to reflect the real emotional feelings about environment, however this kind of methods still lacks authenticity, because it ignores the various behaviors and corresponding psycho-physiological reactions of participants when they are really in urban spaces. To avoid all the above deficiencies, some latest methods utilize mobile or wireless devices to capture participants' psycho-physiological changes when they move in real world, combining with GIS information to analyze the environmental impacts on emotional feelings.

In this research, we tried to find out the effects of both subjective cognition and urban environment on pedestrians' perception of security, by investigating participants' fear of crimes and using wearable devices to record electroencephalographic (EEG) patterns during walking.

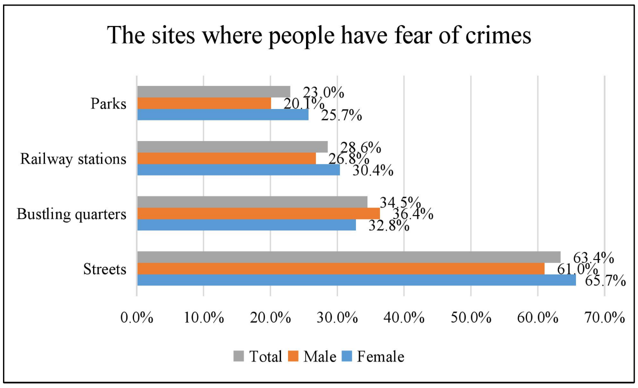

Figure 1 5th questionnaire survey on unease in social life by University of Tokyo

2. LITERATURE REVIEW

In previous researches, perceived security or fear of crimes in various urban walking environment had been analyzed, the conclusion provides a rich reference for how to select environmental influential factors. For neighborhood of residential districts, social incivilities and disorder has significant negative effects on perceived security, which is consistent with broken window theory (Ronald, et al., 2012); contrarily, physical protection or upkeep against crimes in community could improve perceived security of residents (Aldrin, 2012; Hur, 2014). For other walkable urban areas out of residential districts like commercial areas, diversity of land uses, visibility, setting of refuges, existence of transit hubs and other environmental factors were found determined for pedestrians' fear or easiness when they travel in these spaces (Foster, 2013; Loewen, et al., 1993; Haans, et, al., 2012). Leisure places like parks and green spaces were also involved as research scenarios in similar researches (Maruthaveeran, 2012; Mouratidis, 2019). In addition to influence from built environment, the spatial configuration of street network as another important component of urban environment has unnegligible effects on pedestrians' perception (Hidayati, et al., 2020; Koch and Marcus, 2009; Reis, et al., 2005). In Japan, railway is one of the most common ways of travel, neighborhood of busy railway stations has rich walking activities, but the relevant environmental optimization is insufficient. Besides, land uses usually vary from commercial areas to residential or industrial areas, pedestrians tends to have continuous but inconsistent walking experience when travel around railway stations, therefore, analyzing their perceived security in such situations could be helpful and practical for urban planning. This research set the neighborhood of railway stations as experimental scenario, and analyzed the varied mental feelings of pedestrians in terms of perceived security in different street segments.

In addition to external stimuli derived from environment, subjective cognition of personal security and self-defense would also determine people's attention of perceived potential danger and sensitivity of perception. People's subjective cognition includes their acceptable risk-benefit trade-offs towards the events they are likely to experience, which determines their dread and estimated severity (Fischhoff, et al., 1978). But the limitations of cognition and misleading experience may cause participants' perceived risk to be misjudged with unwarranted confidence, as a result, their self-reported perception of security may be amplified or narrowed (Slovic, et al., 1980). Besides, traditional methods of investigating participants' perceived security or risk tend to ignore their judgement bias, because participants usually rely on inferences based on their experience about the risk of crimes (Slovic, et al., 1979). The researches about fear of crimes usually involve the investigation of cognition about security issues and self-defense, and to eliminate the cognitive and memorial bias, the design of questioning in survey has been improved through many versions, from directly asking participants' estimated risk of encountering crimes to investigating their self-assessments or emotional responses about perceived threat of victimization, personal sense of impact of victimization and sense of control over risk (James, 1981; Farrall, et al., 1997; Jackson, 2004), and from the form of intensity measures to frequency measures (Ferraro, et al., 1987; Jackson, 2005; Farrall et al., 2009). The fear of crimes can be involved in perceptive analysis as pedestrians' cognitive factors. Therefore, in researches of analyzing pedestrians' perceived security in urban environment, participants' cognition about fear of crimes and self-defense should be investigated as an indirect influential factor instead of ignoring it or mixing it up with perception of risk. Other effects caused by demographic features can also be dissolved in the investigation of cognition.

To capture pedestrians' perception, directly measuring psycho-physiological indicators associated with emotional feelings is currently the most sophisticated and accurate approach, which reflects real-time perception changing with the external environment. People's emotions are divided into primary and secondary emotions. Primary emotions refers to the reactions to external events, with which people are born wired into brains, while secondary emotions refers to the emotional reactions to primary emotions, which are not wired into bodies and brains, but are learned from families, culture, and others (Russell, 1980). In complex urban environment, although pedestrians' movement faces interference in diverse aspects, their judgment and perception of potential security threats will be based on certain cognition, therefore the measurement of secondary emotions is indispensable for representing people's emotional responses towards environment, and both objective and subjective measuring methods will be required. Since the origin of "Mental Mapping" in 1960s, several similar new concepts of using emotional feelings of users to improve urban planning have emerged, such as crowdsensing, psycho-physiological monitoring, human sensory assessment, and the methods of capturing perception of security developed from questionnaire investigation, interview survey (Warr, 1980; Nasar and Fisher, 1993) to matching psych-physiological data with geographical environmental features (Silva, et al., 2017; Hijazi et al., 2016; Roe et al., 2013). Some latest researches using technology of mobile or wearable devices to record psych-physiological data generally include the design of field experiments, such as allowing participants to walk freely, or asking them to follow a predetermined route, in order to measure perception changes in different urban spaces. The most analyzed psych-physiological indicators include galvanic skin response (GSR), skin conductivity, heart rate and electroencephalography (EEG). Among these indicators, the EEG has the highest complexity and represents the activity of different brain regions, can reflect diverse emotional responses to human perception and is suitable for real-world analysis (Eberhard, 2009). Therefore, this researches selected EEG as the technical methods to measure and record pedestrians' real-time perceptive changes during walking in different street segments.

3. METHODOLOGY

Pedestrians' perception is influenced by diverse factors of ambient environment. Most researches that analyzed pedestrians' real-time psycho-physiological reactions towards walking environment set significantly different environments directly in walking experiments to observe differences in participants' psycho-physiological responses, instead of subdividing the walking environment (Zeile et al., 2015; Aspinall, et al., 2015; Bergner et al., 2013;

Debener et al., 2012; Roe et al., 2013; Mavros et al., 2012; Hassan et al., 2018). To analyze the correlation between environmental factors and perception specifically, one idea is to subdivide the walking environment into several subsegments and quantify environmental features of each subsegment in an micro-scale level (Kim et al., 2019).

The influential environmental factors of pedestrians' perception in urban spaces primarily include urban infrastructure, architectural style, and street configuration. The urban infrastructure and architectural style can be classified as built environment, which is the main analysis object of previous researches. Infrastructure like lighting poles, pavement, parking lots and parks are related with the comfort that pedestrians feel during walking, and the architecture style like visible gates and windows, quantity of low- or high-rise buildings are related with the existence of ambient population, who could provide public surveillance for road users (Douglas et al., 1992; Kirk, 1988; Jose et al., 2020; Hino et al., 2014).

The street configuration has different characteristics from the built environment, because it describes the structural relation and connection mode. Therefore, it's better to measure it by topological indicators rather than metrical ones. The most commonly used method is Space Syntax theory, according to which the spaces can be broken down into components, analyzed as networks of choices, then represented as maps and graphs that describe the relative connectivity and integration of those spaces (Hillier and Hanson, 1984). The most important and basic index is Depth, which means the path length that follows the shortest path from the selected root line (or segment) to all other lines (or segments) within the network system (Turner, 2004). By using Depth, It can calculate two most commonly used indexes, Integration and Choice. Integration is a normalized measure of distance from any an axial line or a street segment of origin to all others in a system. In general, it measures how close the origin space is to all other spaces in the entire system or within a predetermined distance (radius). The higher the value is, the better accessibility the original space has (Hillier and Hanson, 1984). Choice measures how likely an axial line or a street segment it is to be passed through on all shortest routes from all spaces to all other spaces in the entire system or within a predetermined distance (radius). The higher the value is, the better betweenness the origin space has (Hillier et al., 1987). Although most studies have ignored the effects of street configuration, a small number of researches explored the relations of this topological factor and pedestrians' perception (Awtuch, 2009; Antonio et al., 2005; Hijazi et al., 2016).

Table 1 Selected indicators of environmental factors.

	Built environment	Street configuration
Indicators	Street lights	INT_400
	Visible windows	INT_800
	Entrance of buildings	INT_1200
	Low-rise residence	CHO_400
	High-rise apartment	CHO_800
	Stores	CHO_1200
	Parking lots	Centrality
	Parks	Connectivity

The selected indicators for influential factors of environment are listed as **Table 1**. All indicators of built environments were recorded in quantity by on-site manual investigation. All indicators of street configuration were Space Syntax indexes, calculated by the Space Syntax software DepthmapX. INT and CHO refer to Integration and Choice respectively, both of them measured the spatial performance in different scales (400 / 800 / 1200). The radius of 400m / 800m / 1200m from the subject street segment, which respectively correspond to the walking distance of 5min / 10min / 15min. Connectivity and Centrality of street segment were involved, because these 2 indicators are related with the possibility that criminals access to or escape from the street subsegments and how out-of-the-way these street subsegments are.

Before the field walking experiments, the survey of participants' cognition of fear of crimes and self-defense was conducted. According to previous researches, five factors were found to contribute to individual's fear of crime: actual criminal victimization, second-hand information about criminal victimization distributed through social networks, physical deterioration and social deterioration, the characteristics of the built environment, and group conflict (Moore and Trojanowicz, 1988). Therefore the physical condition and cultural background of participants should be investigated, and their daily social intercourse and their knowledge of criminal information from medias should be involved. In terms of the form of questioning, intensity measures could capture both everyday worries or fears and anxiety about future-oriented risk, thus may lead people to misrepresent the frequency with which they actually worry or are fearful in their daily lives (Farrall et al., 1997; Jackson, 2006). The frequency measures may better find out how often people have experienced memorable events of worry about being hurt by crimes over the past specific periods (Jackson, 2005; Gray et al., 2011). Therefore the questions should involve both intensity and frequency measures. Other consideration includes trying to investigate more emotional responses of participants other than their fears, by using adequate expression to investigate only the fears of crimes, instead of using images of criminal situation to investigate participants' feelings (Jackson, 2006; Knauper, 1998; Sterngold et al., 1994; Girling et al., 2000). The items investigated in the survey of cognition are listed as **Table 2**. In addition to the cognition of fear of crime and sense of self-defense, some personal experience and life style of participants were investigated as well, to know about how often participants choose walking as travel mode and the environment of their daily walking, and their familiarity with the environment of experimental sites.

Combined with the investigation of environmental features and subjective cognition, we were able to have an understanding of the internal and external factors that affect the perceived security of pedestrians. In actual urban areas, there were several occurred security issues that could represent the actual security of some places, but people's perception of security in such places may not be correspond with actual condition. The reason is that people's perceived security is affected by their perception of ambient environment and their cognition/attitude towards security issues, and if they know well about the actual security condition of the place they walk in, they may perceive less potential danger than other visitors do. Therefore we need to explore both cognition and participants' familiarity with the environment of the experimental sites. The relationship of perceived security and actual security is shown as **Figure 2**.

The types of analyzed brain wave involve four main independent bands: Theta wave (4-8 Hz), Alpha wave (8-15 Hz), Beta wave (15-30 Hz) and Gamma wave (25-140 Hz). A wireless and wearable EEG headset B-AlertX was used for recording the brain wave activity during walking experiments. B-AlertX weighs only 110g, putting a very small physical burden on the participants and having good stability even when walking. It consists of 21 electrode sensors positioned on the wearers' scalp according to the international 10-20 system, collecting the sample data at a frequency of 256 Hz. According to previous researches, in comfortable urban environment, the level of Theta wave in frontal pole (especially measured by Fp1 electrodes) tends to be higher than that in uncomfortable urban environment (Kim et al., 2020); in urban environment with hot weather, noises and disgusting smells, Beta wave in temporal lobe (especially measured by T3 electrode) tends to increase (Choi et al., 2015). And for emotional feelings, anxious arousal would be associated with greater activation of Alpha wave in the left posterior region, particular in the P3 electrode site (Heller et al., 1997); worried status

Table 2 Investigated items in survey of cognition.

Categorization	Investigated items
Beliefs and attitudes of self-defense from crimes	External reminders about sense of self-defense Media messages about crimes Interpersonal communication about crimes Resistance to going out at night Practical actions of self-defense Acquaintances' sense of self-defense
Emotional responses of specific behaviors	Emotional feelings of daily night walking from railway station(or university) to residence Emotional feelings of daily morning walking from residence to railway station(or university) Emotional feelings of daily night walking in the neighborhood of residence Emotional feelings of night walking in a quiet street then meeting a male
Perceived threat of victimization	Worry of being robbed in a quiet residential area Worry of being robbed in a bustling commercial area Worry of being sexually harassed in a quiet residential area Worry of being sexually harassed in a bustling commercial area Worry of being home-invaded at night
Sense of impact of victimization	Difficulty of mentally recovering from a robbery Difficulty of mentally recovering from a sexual harassment Difficulty of mentally recovering from a home-invasion Ability of fighting against or escaping from a robber in the street Ability of fighting against or escaping from a sexual harasser in the street
Sense of control over risk	Comment on security condition in the neighborhood of residence Comment on security condition in the neighborhood of railway station (most used) Estimation of possibility of getting helped when encountering aggressive behaviors at night Comment on the condition of public surveillance in the neighborhood of residence Comment on the condition of public surveillance in the neighborhood of railway station (most used)
Personal experience of crimes or aggressive behaviors	Experience of encountering robbery or sexual harassment in public space during last 3 years Experience of witnessing robbery or sexual harassment in public space during last 3 years Experience of encountering attempted or accomplished home-invasion during last 3 years Experience of encountering aggressive behaviors in public space during last 3 years Memorable victimization that caused lasting physical, mental or psychological impact since childhood

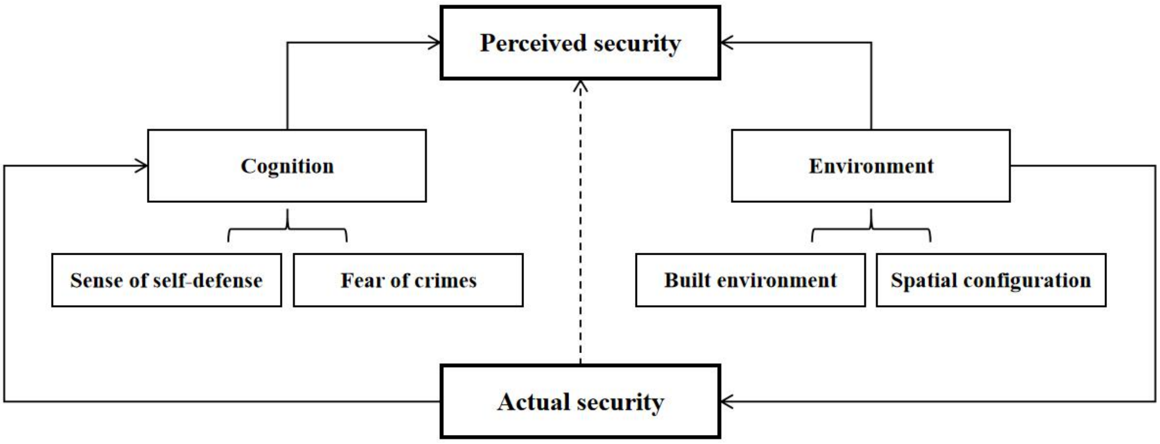

Figure 2 The relationship of perceived security and actual security

may arouse more gamma power in the left temporal area, particularly in the T3 electrode site (Oathes et al., 2008). To involve the emotional responses toward physical environmental pressure, we used the records of above four types of brain wave to calculate the correlation between EEG pattern and environmental features.

The trial experiment was conducted in the neighborhood of Machida railway station in Tokyo, and the designated walking route covered different pattern of areas, starting from busy commercial district to quite residential district, ending at the busy commercial district (**Figure 3**). One healthy university male student was enrolled as participant. Before going to the experimental site, B-AlertX was equipped on participant's head and the resistance value was adjusted to the appropriate level. The participant was required to answer the questionnaire survey about basic information, personal experience, life style and cognition of fear of crimes and self-defense. The author then accompanied the participants to the experimental site by railway, and the participants covered the EEG headset throughout the whole process to avoid unnecessary embarrassment. Before starting walking, participant was instructed to pay attention to the security of ambient environmental during walking and try not to care about other factors and ignore the existence of author. The author then led the participant along the designated walking route without any communication, carrying a laptop connected to the B-AlertX device via Bluetooth, recording brain wave data within an effective range. The exact time points when participants entered and left each street subsegment were recorded. After finishing walking, the participant was led to retrospect the walking process and and was asked to give a subjective comment on the perceived security level of each street subsegment.

4. RESULT

After removing the outliers, we matched the brain wave data of per second to the recorded timeline and yielded **Figure 4**. The variation pattern of EEG, showed in **Figure 5**, was calculated by the root mean square score of each type of brain wave band in each street subsegment. The higher the ratio, the higher the average arousal level of this brain wave in this subsegment.

The Gamma wave and Alpha wave are both related to negative emotional feelings, but they show different variation pattern in subsegment 3 and 6, the reason may be that Gamma wave had strong level of arousal in subsegment 2, and decreased significantly in subsegment 3 and 6, indicating that participant's feeling of worry was quite different in these places. The variation of Alpha wave was relatively smooth, indicating that participant's anxiety did not have large ups and downs. The Beta and Theta wave represent emotional response to two contrary environment conditions, and they only showed different variation

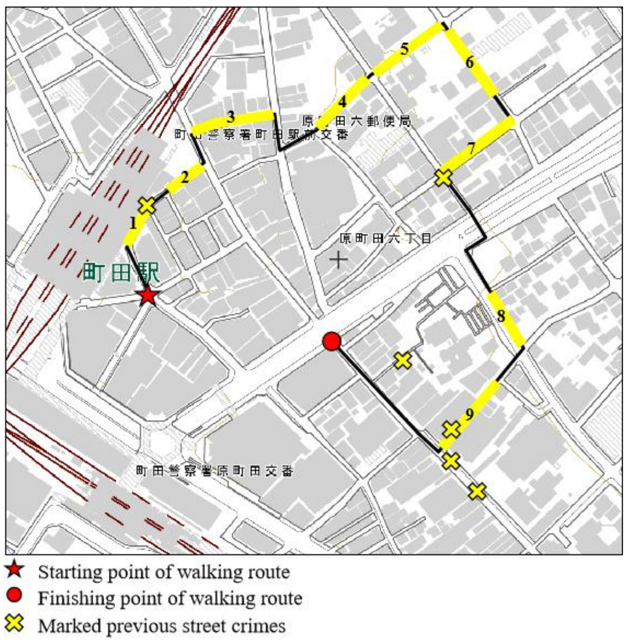

Figure 3 The trial walking experiment in neighbourhood of Machida railway station, Tokyo

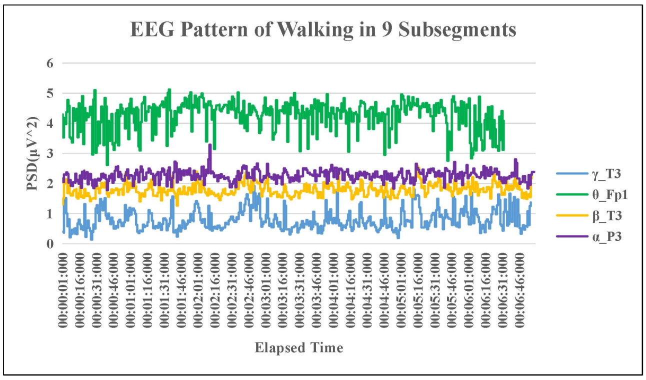

Figure 4 Overall EEG pattern during walking process

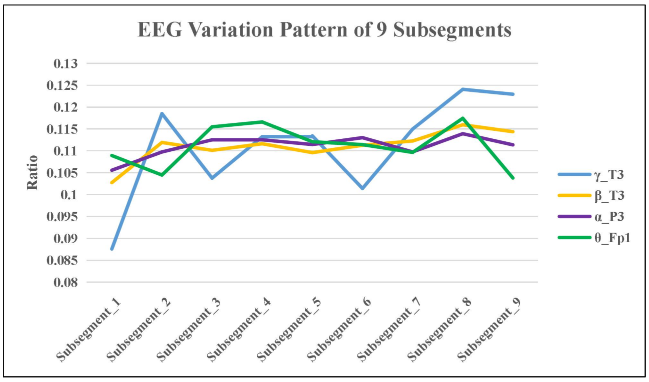

Figure 5 Overall EEG Variation pattern of 9 subsegments

pattern from subsegment 1 to 2, and 2 to 3, indicating that the participant's perception of the environmental contrast in other subsegments was not strong. From the overall EEG variation pattern, we found that the emotional feeling of worry varied more significantly than other emotional responses, and variation of Theta wave showed obvious ups and downs as well. This may indicate that perceived comfort of walking had some effect on participant's perception of worry.

The Pearson's correlation coefficient of EEG and environmental features was calculated as shown in **Table 3**. For built environment, only Theta wave showed significant correlation with quantity of street lights, which is unexplainable, because the time of trial experiment was daytime, and the environmental performance has no relation to illuminance condition.

For street configuration, Gamma wave showed significant correlation with CHO_400, while Beta showed significant correlation with INT_400/800 and CHO_400/800/1200, and Alpha wave showed significant correlation with INT_400 and CHO_800/1200. The centrality and connectivity have little influence on participant's emotional response. Combined with the result of ANOVA and Tukey-Kramer test, the subsegments that showed significant difference of four types of brain wave band were marked in **Figure 6**. For Theta wave, street subsegment 2 and 9 had most significant difference with other places, and for Gamma, Alpha and Beta wave, subsegment 1 was the most unique place. Coincidentally, the Theta wave is positively related to comfort, and Gamma, Alpha and Beta wave are positively related to discomfort and negative emotional feelings. This indicates participant's perceived security is good in subsegment 1 and not good in subsegment 2 and 9. Considering the effects from environment, we took the spatial index CHO_400 for illustration. The subsegment 1 has the lowest level of betweenness, therefore the volume of traffic would be few in this place. Subsegment 2 has higher level of betweenness, and is near an park and several stores, therefore it attracts more pedestrians. Similarly, subsegment 9 is near the busy commercial area and has good level of betweenness, and the possibility of encountering other pedestrians would be higher. According to the participant's explanation in a post-experiment interview, he thought it would be more dangerous in crowded place during the daytime. This would make

Table 3 Pearson's correlation coefficient of EEG and environmental features.

Built environment	**γ_T3**	**θ_Fp1**	**β_T3**	**α_P3**
Street lights	0.10	0.64*	0.16	0.46
Visible windows	0.30	0.31	0.26	0.39
Entrance of buildings	0.13	0.21	0.20	0.23
Low-rise residence	0.16	0.13	0.34	0.14
High-rise apartment	0.28	0.11	0.34	0.18
Stores	0.18	-0.05	0.20	0.17
Parking lots	0.12	0.50	0.30	0.51
Parks	0.00	-0.27	-0.03	0.09
Street configuration				
INT_400	0.41	0.24	0.68*	0.71*
INT_800	0.50	0.02	0.71*	0.56
INT_1200	0.29	0.09	0.50	0.55
CHO_400	0.76*	0.20	0.79*	0.72
CHO_800	0.53	0.44	0.69*	0.78*
CHO_1200	0.56	0.22	0.68*	0.65*
Centrality	-0.09	-0.30	-0.11	-0.08
Connectivity	0.26	0.06	0.20	0.12

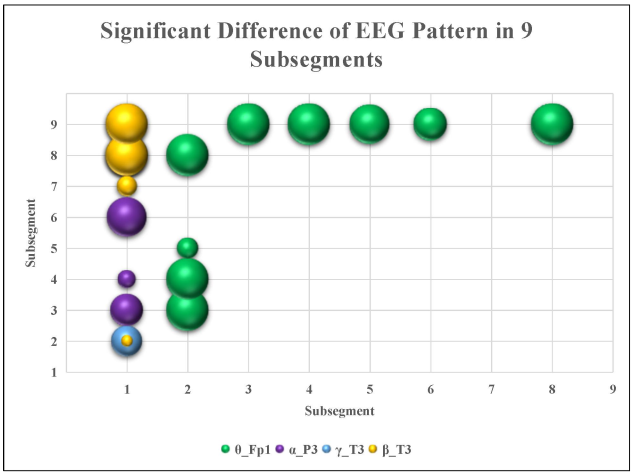

Figure 6 Significant difference of EEG pattern in 9 subsegments

sense that he had significant perceptual changes in these three places.

5. CONCLUSION

This research made an effort to clarify the effects of cognition and environment on pedestrians' perception of security, by investigating participant's cognition of fear of crimes and self-defense and using the technology of electroencephalogram (EEG) to measure the level of psycho-physiological reaction of pedestrians in real-time walking. The result of trial walking experiment showed that the features of topological configuration of streets are correlated with participant's emotional feelings of worry and anxiety about security issues, but the built environmental features have little influence on participant's perception of security. The participant's cognition of fear of crimes and self-defense could be considered as effective on perception, because the survey showed participant's low concerns about potential risk of security issues in streets, and low level of sense of self-defense.

However, the limitations of this research are obvious. The very few quantity of experimental groups makes some arguments lacking support from statistical results, while the experiment lacks controls between human and environmental factors as well. In the future, more participants with different demographic features should be enrolled for control groups, for taking account of the difference of perception of security caused by physical and cognitional factors. The field experiments should involve different sites and time periods to cover diverse walking environment, and the selected environmental features in correlation analysis should be modified to make it more informative.

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