学位論文の要旨

Abstract of Thesis

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学位論文題目 Title of Thesis（学位論文題目が英語の場合は和訳を付記）

Research on Haptic Angle Discriminability and Development of Angle Magnitude Sorting System
(触覚角度弁別特性と角度順序配置システム開発に関する研究)

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In daily life, people usually use touch to perceive the physical properties of objects, such as material, roughness, temperature, vibration frequency, shape, and weight, etc. Through hand or finger touch, the brain processes tactile information, such as comparisons and memories, to help us explore the outside world. Almost all previous studies have shown that the touch perception derived from the skin varies from individual to individual, such as the discrimination of geometric characteristics of objects. In our previous research on geometric characteristics of tactile discrimination, the shape of two-dimensional raised-angle was used as a tactile stimulus, which also proved that people's ability to discriminate these angles is also different, such as normal people and Alzheimer disease patients. But there were significant differences in the ability to discern angles between these groups. Such differences could help assess touch cognition function in different populations and even lead to early tests for symptoms. Although we have tested and verified that this method can be applied well, but limited by its test efficiency and cumbersome test process, such an evaluation method can only stop at the laboratory. Therefore, the purpose of this thesis is not only to use the shape of two-dimensional raised-angles as haptic stimuli, and to propose a test method using angle sorting to evaluate the tactile sensations of different groups of people, but also to use MRI to further explore the nature of the human brain's assessment of physical quantities through the haptic of the hand.

In the first part, we use the angle-stimulated Two-alternative forced choice (2AFC) test on healthy people and calculated the discrimination threshold for each subject using a logic curve. It is also proposed that the same result obtained in the 2AFC test is used to fit the Gaussian cumulative function to calculate its variance σ, which we call the discrimination index and use as a parameter to evaluate the angle discrimination ability. Through the mathematical model, we proved the conversion relationship between the logic curve and the Gaussian cumulative function. Using this relationship, the conversion between the discrimination threshold and the discrimination index can be achieved. At the same time, it is further proved by calculating and comparing the almost same the coefficient of multiple determination (R-square) and the sum of squares due to error (SSE) when fitting the two functions on the experimental data. Therefore, this result proves that the discrimination index can also be used to evaluate the angle discrimination performance.

In the second part, we purposed a new angle sorting method to evaluate the angle discrimination ability and calculate the angle discrimination index based on the result. Here, we conducted an angle sorting test on healthy people and established an angle discrimination index calculation method based on the sorting results using maximum likelihood estimation. To compare the test efficiency and test process of this method, we also conducted 2AFC test for the healthy population and calculated the angle discrimination index. In the analysis using the maximum likelihood estimation, it is assumed that participants choose the minimum angular stimulus placement every time in the sorting, and the angular stimulus that has been placed cannot be selected again. At the same time, when the participants determined the angle stimulus at a certain position each time, the angle selection was subject to the normal distribution, and the mean of the normal distribution was the minimum angle value of the angle not selected, and the variance was set as σ. Therefore, in the analysis of sorting from small to large, those angle stimuli not selected before at each position is a normal distribution subject to the same variance, and the probability of the selection of the angle stimulus is the corresponding probability density under the normal distribution. The probability of the entire sorting result is the product of the probability of each position. According to this mathematical relationship, we obtain the functional relationship between the probability of the sorting result and the variance σ. To calculate the optimal solution of this function relation is to obtain the angle discrimination threshold. This evaluation process makes testing more efficient than method for calculating discrimination thresholds after repeated pairwise comparisons. The test results found that the angle sorting method of evaluation reduced the test time from 2.5 hours in the past to about 5 minutes.

In the third part, according to the angle sorting task, we design the angle sorting test system. The system is designed to meet the task from the device structure, hardware, and software design, to achieve the data processing and simplify the test process, making the system more convenient for non-professionals to use. In terms of structure, considering that a certain number of angle patterns need to be used in the test to sort participants, the integrated design of the structure also reserves space for storage of these stimuli. In addition, in order for the system to recognize different angles well, let different angle values correspond to unique key code blocks. In the hardware, the recognition module for the system reading angle and the main function module for the user's operation is designed. Each angle corresponds to a unique keycode, which activates a different digital signal. This design converts the mechanical structure into a binary signal that can be recognized by the computer. The ordering angle values of the participants are then decoded and identified according to the relationship between each Angle keycode and the binary signal. The angle recognition module collects and converts data in this process, and then sends these to the master control module for subsequent processing, such as calculating the discrimination threshold of the angle sorting results, displaying the results, transmitting data, and other operations. The software is designed for the system, and the angle threshold evaluation algorithm and graphical interface are embedded in the design to make it easier for non-professionals to use. Through the feedback of participants and experimenters, the system can obtain the test results in time and simplify the test process.

Moreover, to test application of system and the sorting evaluation method to different groups, we tested healthy older adults, patients with mild cognitive impairment, and patients with Alzheimer's disease using the angle sorting method. In our previous studies, we have also used the angle discrimination method to test these three groups of people, and found that the angle discrimination thresholds between different groups are significantly different. The discrimination threshold obtained by measurement can be used to evaluate patients with cognitive impairment and Alzheimer's disease. But in this study, we also tried to use this efficient test method such as angle sorting to evaluate patients with cognitive impairment and Alzheimer's. Each participant needs to perform two angle sorting, respectively, under the conditions of blinding and not blinding the eyes, and the angle difference of sorting is 5°. The test results showed that all the people in the visible condition were better than the invisible discrimination threshold, which may be the visual and tactile information integration is helpful to improve the individual's cognitive ability. However, when healthy people and people with mild cognitive impairment are sorted under visible conditions, there are still some people who cannot fully guarantee the correct sorting. And available discrimination

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thresholds can be obtained in the sorting of this angle difference for everyone. In patients with Alzheimer's disease, even under visible conditions, there are still several patients who cannot measure the discrimination threshold, and this is because they mistakenly regard large angles as small angles in the sorting process. Under invisible conditions, there are significant differences in the angle discrimination threshold measured by the angle sorting method among the three groups of healthy elderly, patients with mild cognitive impairment, and patients with Alzheimer's; that is, the discrimination threshold of healthy people is the smallest, Patients with mild cognitive impairment are larger, while patients with Alzheimer's have the largest discrimination threshold. The test results prove that the discrimination threshold measured by the angle sorting method can be applied to the early clinical examination and evaluation.

In summary, we propose an Angle ordering shape discrimination method for the evaluation of tactile cognitive function. In addition to the proposed method, we also develop an Angle ordering system for testing. Discrimination thresholds were calculated and compared with testing young adults, healthy older adults, people with mild cognitive impairment and Alzheimer's disease. We used the discrimination threshold as a measure and found that the results differed significantly between different populations. Not only do we use this method to quantify tactile discrimination, but we also use MRI to further explore areas of the brain that are represented in the evaluation of physical quantities (memory and comparison). Based on the current situation, future research will focus on the neural mechanism of how the human brain integrates visual and tactile information into quantitative evaluation.