Study on Improving Fluid Intelligence through Cognitive Training System Based on Gabor Stimulus

Qiu Feiyue
College of education and technology
Zhejiang University of Technology
Hang Zhou, 310014, China
qfy@zjut.edu.cn

Wei Qinqin, Zhao Liying, Lin Lifang
College of education and technology
Zhejiang University of Technology
Hang Zhou, 310014, China
zhejiangsara@163.com , zly@zjut.edu.cn, llfcynthia@163.com

***Abstract*—General fluid intelligence (Gf) is a human ability to reason and solve new problems independently of previously acquired knowledge and experience. It is considered one of the most important factors in learning. One of the issues which academic people concentrates on is whether Gf of adults can be improved. According to the Dual N-back working memory theory and the characteristics of visual perceptual learning, this paper put forward cognitive training pattern based on Gabor stimuli. A total of 20 undergraduate students at 24 years old participated in the experiment, with ten training sessions for ten days. Through using Raven's Standard Progressive Matrices as the evaluation method to get and analyze the experimental results, it was proved that training pattern can improve fluid intelligence of adults. This will promote a wide range of applications in the field of adult intellectual education.**

Keywords-Fluid intelligence; Dual N-back; perceptual learning ; Gabor visual target; working memorsy

I. INTRODUCTION

Cattell proposed two types of cognitive abilities: fluid intelligence (Gf) and crystallized intelligence (Gc). Gf is critical for a wide variety of cognitive tasks [1], and is considered one of the most important factors in learning. There is considerable agreement that Gf is robust against influences of education and socialization, and is commonly seen as having a strong hereditary component [2-3], Gf can not be changed in adult. However, the study show that working memory is related to fluid intelligence [4], and Gf can be improved with training on working memory [5]. In the area of perceptual learning, Levi and Polat found that perceptual learning with Gabor visual identify task will improve people's space vision [6-7].

Because fluid intelligence was hypothesized to increase until adolescence and then slowly decline, existing research in the field of intellectual education focused on early education of children, and less study on adult. In order to study the possibility of improving fluid intelligence in adult, through combining the perceptual learning with Gabor visual indentify task, we developed a cognitive training system based on Gabor stimulus, also the experimental results showed that it is possible to improve fluid intelligence of adults.

II. PRINCIPLE OF COGNITIVE TRAINING SYSTEM

A. Dual N-back Working Memory Theory

The concept of working memory was put forward by Baddeley and Hitch in 1974 [8]. The original model of working memory was consisted of three main components: the central executive system which acts as supervisory system and controls the flow of information from and to its slave system; the phonological loop and the visuo-spatial sketchpad. N-back task is based on the Baddeley's experiment, and used frequency in the construct of the theory. It takes two tasks in the same time: one is the reasoning task, and another is the secondary task which can interfere in the component of working memory. The principle of N-back is that two tasks competed to use the same limited resource. A series of research showed that it is effective that the secondary task interfere in the component of working memory.

Dual N-back improved N-back task, which includes two stimulators: visual stimulate and auditory stimulate. In this task, participants saw two series of stimuli that were synchronously presented at the rate of 3 s per stimulus. One string of stimuli consisted of single letters whereas the other consisted of individual spatial locations marked on a screen. The task was to decide for each string whether the current stimulus matched the one that was presented n items back in the series. As n increases, it has excessive memory load affect the activation in the prefrontal cortex, and then to improve fluid intelligence.

B. Medicine Principle of Gabor Visual Task

The receptive field of a sensory neuron is a region of space in which the presence of a stimulus will alter the firing of that neuron [9]. In visual systems, receptive fields are volumes in visual space. Hubel and Wiesel developed the theory that receptive fields of cells at one level of the visual system are formed from input by cells at a lower level of the visual system [10]. Maffei thought that the deepness of functional column in visual area may be encoding the frequency characteristic of visual space, and neuron in different deepness sensitive by the stimulation of spatial frequency.

Gabor function is an excitation waveform that can be used for finite-difference, time-domain and S-parameter estimation,

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and 2-D Gabor functions are used as models of the receptive fields of simple cells. Levi and Polat study showed that perceptual learning with Gabor signal by efficiently stimulating neuronal network effectively promoted spatial interaction. They used Gabor visual tasks with different sizes, direct, spatial frequency and contrast to training visual system, and found it is possible to improve basic representations within an adult visual system through perceptual learning.

III. STUCTURE OF COGNITIVE TRAINING SYSTEM

The cognitive training system use MATLAB 7.0 and Visual C++ 8.0 as front-end developing tool and SQL Server 2000 as background database, which is simple to operate, modify and expanded easily.

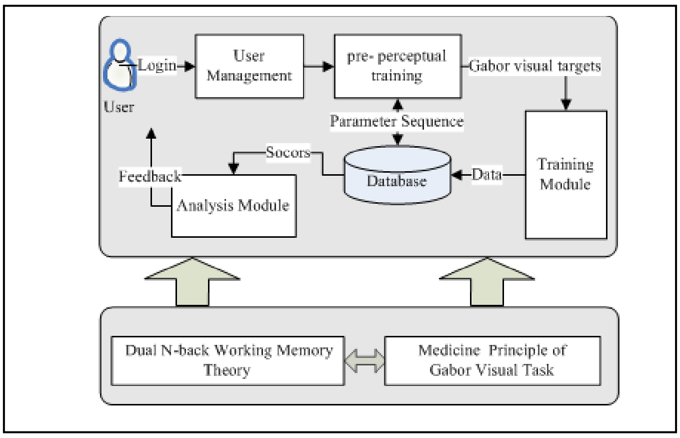

Figure 1. Structure of cognitive training system.

Cognitive training system includes four modules: user management module, pre-perceptual training module, training module and analysis module: the user management module is to manage personal information about users; the pre-perceptual training module is to provide different Gabor visual targets with different sizes, directs, spatial frequency and contrast; the training module includes cognitive training method with Gabor stimulation; and the analysis module responsible for data processing and statistics.

IV. TRAINING MECHANISM

According to the principle of Dual N-back, we get the knowledge that it has no direct relationship between the shape of visual stimuli and the improvement of fluid intelligence. Obviously, improving fluid intelligence with training working memory is related to the internal training mechanism. So it is feasible to changed visual stimulus as the Gabor visual target. We Improved the Dual n-back task, and put forward a new cognitive training pattern based on Gabor stimulus. It has two stimulators, one is visual stimulate, which content the cognition training of Gabor visual target, and another is auditory stimulate, which consisted of single letters. During the training process, visual stimulus (Gabor visual target) as the reasoning task, and audio stimulus (Letter) as the secondary task common role in the central control system of brain.

Before the training task, the users should take a pre-perceptual training task, and the purpose is to provide personalized cognitive training according to individual characters. Because of situations about the defect of spatial frequency is difference, therefore users can choose eight different Gabor visual targets with different sizes, directs, spatial frequency and contrast as the visual stimulus thorough pre-perceptual training.

For the training task, Gabor visual targets with two different kinds of spatial frequency at four different directions were presented sequentially on a computer screen at a rate of 3s (stimulus length, 500ms; inter-stimulus interval, 2,500ms). Simultaneously with the presentation of the Gabor visual targets, one of eight consonants was presented sequentially through headphones. A response was required whenever one of the presented stimuli matched the one presented n positions back in the sequence. The value of n was the same for both streams of stimuli, and the Gabor visual targets were determined randomly. Users responses manually by pressing on the letter “A” of a standard keyboard with their left index finger for Gabor visual targets, and on the letter “L” with their right index finger for auditory targets. Non-responses were required for non-targets.

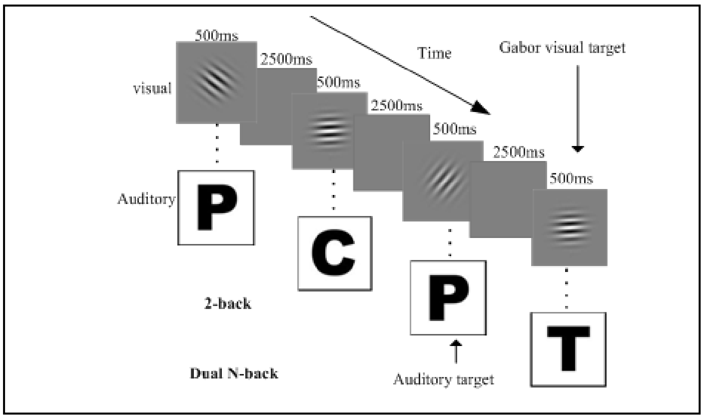

Figure 2. The training mechanism of cognitive training system

The value of n varied form one block of trails to another, with adjustments made continuously for each user based on performance. As performance improved, n incremented by one item; as it worsen, n decremented by one item. Thus, the task changed adaptively so that it always remained demanding, and this demand was tailored to individual participants.

V. SYSTEM IMPLEMENTION

The pre-perceptual training module of cognitive training system is to provide eight different Gabor visual targets. It is the basis for the realization of the training system. There are two different kinds of trainings about Gabor visual target: the recognition training of single optotype and the bright-dart discrimination training. In the situation of recognition training of single optotype, users can set two different spatial frequency with four different directs, and then enter to the stage of Dual n-back training. However, in the situation of the bright-dart discrimination training, users should choose eight groups of three Gabor visual targets, the center is the target the user should recognize, and on the both sides are the interference signals. These eight groups of Gabor visual targets will be the reasoning task of Dual n-back in training Module.

Training Module is the most important part in the cognitive training system. We regulated one training session is comprised 20 blocks consisting of 20+n trails resulting in a daily training time of 25 minutes. In the task, the level of difficulty was varied by changing the level of n, which we used to track the users' performance. After each block, the users' individual performance was analyzed, and in the following block the level of n was adapted accordingly: If the participant made fewer than three mistakes per modality, the level of n increased by 1. It was decreased by 1 if more than three mistakes were made, and in all other cases, n remained unchanged.

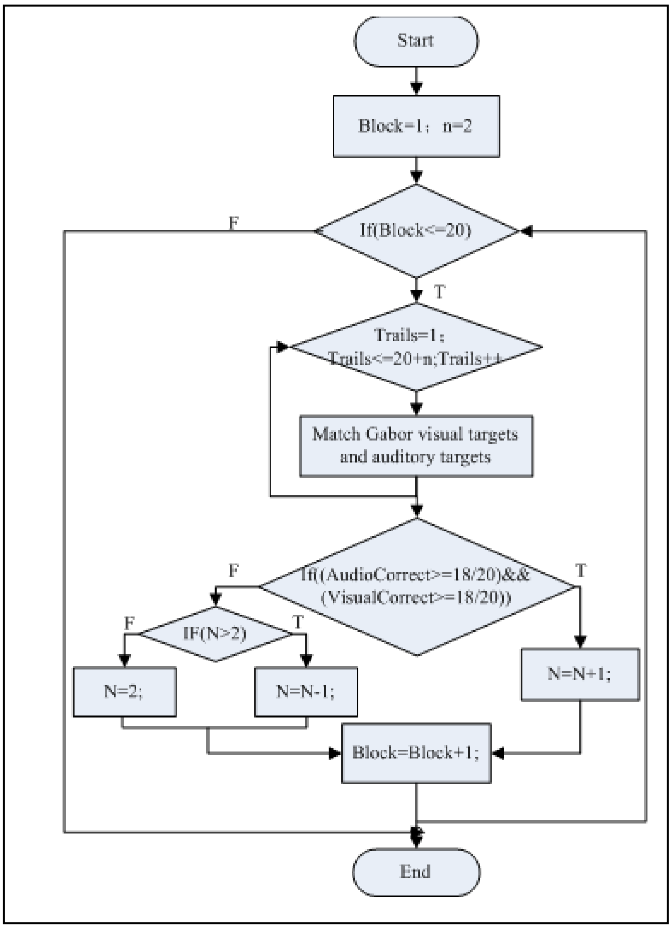

Figure 3. Program flow chat of the training module

The key technology of cognitive training system is realizing Gabor visual target, which is generated by 2-D Gabor functions. The Gabor transform is a special case of the short-time Fourier transform. It is used to determine the sinusoidal frequency and phase content of local sections of a signal as it changes over time. The function to be transform is first multiplied by a Gaussian function, which can regard as a window, and the resulting function is then transformed with a Fourier transform to derive the time-frequency analysis. The window function means that the signal near the time being analyzed will have higher weight. The mathematical model is given below:

$$g_{uv}(x,y)=\frac{k^2}{\sigma^2}\exp\left(-\frac{k^2(x^2+y^2)}{2\sigma^2}\right)\bullet\left[\exp\left(ik\bullet\begin{pmatrix}x\\ y\end{pmatrix}\right)-\exp\left(-\frac{\sigma^2}{2}\right)\right] \quad (1)$$

$$k=\begin{pmatrix}k_x\\ k_y\end{pmatrix}=\begin{pmatrix}k_v\cos\varphi_u\\ k_v\sin\varphi_u\end{pmatrix}$$

$$k_v=2^{-\frac{v+2}{2}}\pi$$

$$\varphi_u=u\frac{\pi}{K} \quad (2)$$

V determined the value of the wavelength of Gabor filter, u denoted the value of the direction of Gabor, and K denoted the total number of direction, parameter σ/k determined the size of Gaussian window.

We used MATLAB7.0 to realize Gabor visual targets. Through the adjustment of model parameters we can achieve the Gabor visual targets with different directs and spatial frequency.

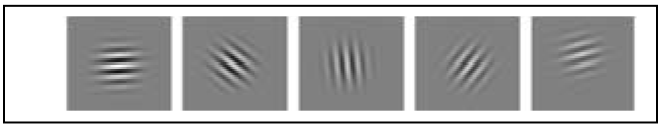

Figure 4. Gabor visual target with different directs and spatial frequency.

VI. DISCUSSION

In order to analyze the effect of cognitive training system, we carried out an experiment involving a total of 20 healthy young participants (24.15 years of age) recruited from Zhejiang University of Technology. In detail, 10 of candidates performed the cognitive training: two of them failed to complete the required training sessions and was thus discarded from the data analysis. These training group was matched to a control group (number=10) which did not have training. The experiment with ten training sessions, and participants trained daily. The standardized fluid intelligence test called Raven's Standard Progressive Matrices (SPM) was adopted, which consists of visual analogy problems of increasing difficulty. Each problem presents a matrix of patterns in which one pattern is missing. The task is to select the missing pattern among a set of given response alternatives. The control group received the pre- and post test at the same intervals as the trained group. In order to reduce the interference factor, we strictly control the training groups trained daily in the same time and place. To keep the pre- and post testing session consistency, we allowed participants to complete the standardized fluid intelligence test in limited time (25min).

We can see in the Figure 5, for each session, the mean level of n-back achieved by the participants is presented. The level of n-back depends on the participants' performance. Analyses of the training data revealed that the participants of training group improved in their performance on the Dual N-back task in ten sessions. We can see in the Figure 6, all the participants in the control and trained group got more IQ scores than pre-test after ten days, because we adopted the same standardized fluid intelligence test. But participants in training group increase more IQ scores than control group. This data indicated that the effect on Gf scores went beyond an increase in working memory capacity. With the enhance performance of trainers, the reasoning ability has been strengthened. Moreover, the performance has strong relationship with the degree of concentration during the cognitive training.

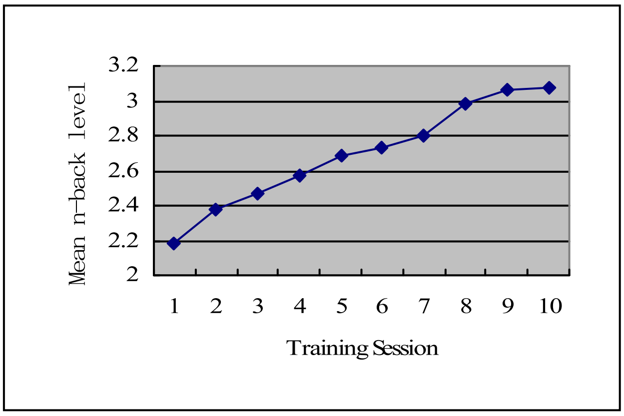

Figure 5. The performanc in the trained task.

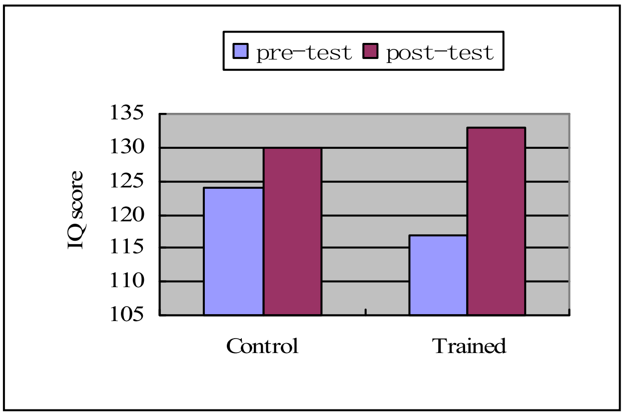

Figure 6. Trainsfer effects.

The cognitive training affect the activation in the prefrontal cortex by excessive memory load in dual tasks, and then to improve fluid intelligence. It is different from training the test itself, and performance can remain and transfer. The experiment investigated it is possible to improve fluid intelligence in adults, and this finding is highly relevant to applications in education, therefore the cognitive training system is of great significance in intelligence education of adults.

During the cognitive training, Gabor visual target with two different kinds of spatial frequency at four different directions asked the user to take the Gabor indentify task, which can effect spatial frequency in visual system and improve vision. We can get a conclusion that the system not only help to improve fluid intelligence but also help to improve vision.

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