Attention Enhancement System using Virtual Reality and EEG Biofeedback

B. H. Cho
Dept. of Biomedical Eng., Hanyang University, Korea
uranus@bme.hanyang.ac.kr

J. M. Lee
Dept. of Biomedical Eng., Hanyang University, Korea
min6392@bme.hanyang.ac.kr

J. H. Ku
Dept. of Biomedical Eng., Hanyang University, Korea
jhku@bme.hanyang.ac.kr

D. P. Jang
Dept. of Biomedical Eng., Hanyang University, Korea
human123@bme.hanyang.ac.kr

J. S. Kim
Dept. of Biomedical Eng., Hanyang University, Korea
jseok@bme.hanyang.ac.kr

I. Y. Kim
Dept. of Biomedical Eng., Hanyang University, Korea
iykim@hanyang.ac.kr

J. H. Lee
Dept. of Psychology, Choong-Ang University, Korea
clipsy@unitel.co.kr

S. I. Kim
Dept. of Biomedical Eng., Hanyang University, Korea
sunkim@hanyang.ac.kr

Abstract

Attention Deficit Hyperactivity Disorder (ADHD) is a childhood syndrome characterized by short attention span, impulsiveness, and hyperactivity, which often lead ? to learning disabilities and various behavioral problems. For the treatment of ADHD, medication and cognitive-behavior therapy is applied in recent years. Although psychostimulant medication has been widely used for many years, current findings suggest that, as the sole treatment for ADHD, it is an inadequate form of intervention in that parents don't want their child to use drug and the effects are limited to the period in which the drugs are physiologically active. On the other hand, EEG biofeedback treatment studies for ADHD have reported promising results not only in significant reductions in hyperactive, inattentive, and disruptive behaviors, but also improvements in academic performance and IQ scores. However it is too boring for children to finish the whole treatment. The recent increase in computer usage in medicine and rehabilitation has changed the way health care is delivered. Virtual Reality technology provides specific stimuli that can be used in removing distractions and providing environments that get the subjects' attention and increasing their ability to concentrate. And Virtual Reality technology can hold a patient's attention for a longer period of time than other methods can, because VR is immersive, interactive and imaginal. Based on these aspects, we developed Attention Enhancement System (AES) using Virtual Reality technology and EEG biofeedback for assessing and treating ADHD children as well as increasing the attention span of children who have attention difficulty.

1. Introduction

After the new technology of Virtual Reality was developed in the 1960s, it has been improved dramatically, and nowadays it is widely used in the field of Entertainment, Arts, Military, Medicine, Education, Robotics, Business application, and so on. So many articles appear in newspapers concerning a new application for VR and there is no doubt about the benefits of VR [1,2].

Burdea proposed the three "I"s of Virtual Reality: Immersion, Interaction, and Imagination [3]. It is clear that Virtual Reality is both interactive and immersive. The extent to which an VR application is able to solve a particular problem depends very much on the human imagination, which means VR is imaginal. As well as those three "I"s, there is one more "I". That is Interest. Manipulating some virtual objects, talking with avatars, and walking through the virtual space, people take an interest in the Virtual Environment (VE). This is not confined to only novices of VR. Interest is one of the major advantages of VR and it is the source of creating a new technology. Consequently, we can define VR as an integrated quartet of "Immersion-Interaction-Imagination-Interest".

In recent years, increased computer usage in Medicine and Rehabilitation has changed the way health care is delivered. Virtual surgery, VR anatomy trainer, On-line patient databases, pre-surgery simulation, digital

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radiography, expert systems, and remote consultation is allowed today with the power of computers [4]. And Virtual Reality Therapy (VRT) is an innovative paradigm of VR in Medicine [5].

1.1. Virtual Reality Therapy

Cognitive-Behavior Therapists believe that cognition intervenes one’s emotions and behavior. They also believe that faith or thought related with abnormal behavior can be monitored and changed. Lastly, if they change one’s cognition, his or her behavior and emotion must be changed sustainedly [6].

In treating mental disorder, existing Cognitive-Behavior therapy has some weak points. Exposure therapy as Cognitive-Behavior therapy provides patients with some stimuli that cause anxiety or fear. But much recent research indicates hat a number of patients have problems with imagining the terrible scenes and sometimes exposure to real situations is dangerous for them [7,8]. VRT has a solution for these problems. An immersive Virtual Environment provides stimuli to patients without possibility of putting them into a dangerous situation. Also, VRT guarantees patient’s privacy and is more economical compared with real exposure therapy. In the last decade, many kinds of VRT systems (for Acrophobia, Agoraphobia, Fear of flight, Fear of public speaking, and so on) have been developed and are clinically proven for their efficacy as Cognitive-Behavior therapy [9,10,11,12,13,14].

1.2. Attention Deficit Hyperactivity Disorder (ADHD)

Attention is supposed to be the information management process in which intensiveness, sustainability, selectiveness and controllability combine and interact. To explain attention deficit, the attention process is generally divided into five components: focused attention, sustained attention, selective attention, alternating attention and divided attention [15]. Table 1 represents a brief description of each component.

Table 1. Attention process Components

Components	Description
Focused attention	The ability to respond to specific stimuli
Sustained attention	The ability to maintain consistent concentration on performing a task
Selective attention	The ability not to be distracted by interfering or competing stimuli
Alternating attention	The ability to alternate the focus of attention
Divided attention	The ability to respond to two or more kinds of stimuli simultaneously

ADHD is the most commonly diagnosed childhood behavior disorder. Children who are diagnosed with ADHD generally have trouble in paying attention, are easily distracted, impulsive, and hyperactive. In other words, they just can't seem to keep still or to focus on the task at hand. The disorder is frequently broken down into three subcategories according to whether the child is hyperactive and impulsive alone, inattentive alone, or a combination of all three (DSM-IV, 1994). ADHD children suffer from serious impairment in relationships with parents, teachers, peers, and siblings as well as major difficulties in academic functioning and such difficulties often continue into young adulthood [16,17,18]. Estimates of the prevalence of this disorder range from 5% to 15% of the school-age population [19,20]. Including people who have attention difficulty, but not ADHD, the number would be even higher.

Although psychostimulant medication such as *Ritalin* has been widely used for many years, current findings suggest that, as the sole treatment for ADHD, it is an inadequate form of intervention. The main reasons are as follows: First, stimulants do not work for all children, and stimulant therapy is rarely sufficient to bring children into a normal range of academic and social functioning. Second, psychostimulant effects are limited to the period in which the drugs are physiologically active. Finally, without exception, studies that have followed children treated with psychostimulant medication for periods of up to 15 years have failed to provide any evidence that the drugs improve the long-term prognosis of children with ADHD [21].

Rizzo proposed the Virtual Classroom for the assessment and rehabilitation of attention deficits. This study shows that VR can be used in the assessment of attention as well as cognitive training and can offer better predictive information regarding performance in the real environment [22].

1.3. ADHD Treatment as Cognitive-Behavior Therapy

For overcoming the limits of psychostimulant medication, another approach to manage ADHD has been the use of behavioral treatment. Since the mid-1970s, a number of studies have been conducted to evaluate the efficacy of behavior modification and therapy for children with ADHD. Behavioral interventions effect short-term amelioration of ADHD symptoms and these effects are comparable in some aspects to those obtained with low doses of stimulant medication. However, behavioral modification techniques are complicated and time consuming, and lack of consistency and follow-through can reduce the effectiveness of the intervention.

For the last few decades, Electroencephalography (EEG) has emerged as another potential diagnostic assessment and treatment for ADHD. Winkler, Dixon, and Parker revealed that there was more diffuse, rhythmically slow wave, specifically theta activity (4-8 Hz), and less faster wave beta sensorimotor rhythm (SMR) activity (12-20 Hz), and a greater incidence of abnormal transient discharges in the group exhibiting scholastic and behavioral problems exhibiting group [23]. Previous studies of EEG have provided some clarification in the mechanisms underlying ADHD. In addition, EEG biofeedback treatment outcome studies for ADHD have reported promising results not only in significant reductions in hyperactive, inattentive, and disruptive behaviors, but also improvements in academic performance and IQ scores [24,25]. Recently, Othmer and Kaiser proposed the use of EEG Biofeedback, or Neurofeedback, with Virtual Reality [26].

Several research studies have shown that Virtual Reality technology provides specific stimuli that can be used in removing distractions and providing environments that get the subjects' attention and increases their concentration [5,22]. The experience of presence in a VE requires selective attention [27]. That is, experiencing presence in remote operations task or in a VE requires the ability to focus on one meaningfully coherent set of stimuli to the exclusion of unrelated stimuli. And Virtual Reality technology can hold a patient's attention for a longer period of time than other methods can, because VR is immersive, interactive and imaginal. And above all, it is interesting.

Considering these aspects, we developed Attention Enhancement System (AES) using Virtual Reality technology and EEG biofeedback for assessing and treating ADHD children as well as improving children's attention who have attention difficulty (not ADHD).

2. Attention Enhancement System

2.1. The Virtual Environment – A Classroom

Because the children and adolescents spend much time in their classroom, they should be attentive to the classroom tasks. Therefore, as our first project, we developed the classroom-based virtual environments for intimacy and intensive attention enhancement.

The small classroom has a whiteboard, a desk on which there are red, yellow and violet flags, a teacher avatar, a female friend avatar, a large window looking out onto a playground with a child exercising on the horizontal bar, an entrance, several pictures hung on the wall, a sofa, a ceiling light, and a wooden floor. Subjects can see themselves, the self-avatar sitting at the desk. That is, subjects can feel as if he or she is in a real classroom. In this basic virtual environment, subjects will perform some training sessions.

2.2. Virtual Reality Cognitive Training

The virtual classroom is intimate and immersive for children, so they easily pay attention to the classroom environment itself. However, the training tasks of our system are not so interesting to them. We developed two cognitive training courses: Virtual Reality Comparison Training and Virtual Reality Sustained Attention Training.

Figure 1. Basic virtual environment of a classroom

These cognitive training sessions look somewhat like other ADHD assessment tools, for example Continuous Performance Task (CPT), Test of Variables of Attention (TOVA) or Wisconsin Card Sorting. The assessment tools have no effect of repetition. Accordingly, if one applies those assessment tools repeatedly, there should be no difference seen with the results, which means that they are for the assessment, not for the treatment or the enhancement. On the other hand, the most important difference between our cognitive training sessions and those assessment tools is that ours have their levels. In our cognitive training sessions, subjects know their level of progress; therefore, they must make an endeavor to make progress to the next level. The higher a level one reaches, the more effort one should make to complete it.

A subject seats at the virtual desk and can see three flags (red, yellow and violet) that are lying on the desk. In all two cognitive training courses, after stimuli are provided, red flag, yellow flag and violet flag are erected one by one. Only when the violet flag is made to stand are the subjects permitted to respond. This is for controlling hyperactive responses. If one breaks this rule, the subject can hear a warning sound (beep) in the virtual environment.

Virtual Reality Comparison Training (VRCT) is for enhancing focused attention and selective attention of a subject. When the training session starts, a subject can see two three dimensional objects on the desk. For example, a sphere and a square pillar. Those objects are sometimes identical and sometimes different. If identical objects are presented, one of those is occasionally yawed, pitched or rolled slightly. Therefore subjects should pay attention to that. If a subject decides those are same, he or she is encouraged to press the left mouse button. Otherwise, he or she must press the right button. For each session, a subject repeats this routine 60 times. We can measure the number of correct answers and the response times. If the number of correct answers is over 57, a subject will go to the next stage in the following session. As the subject progresses through the stages, the length of time he or she can see the objects decreases gradually and the objects provided objects are less distinguishable: for example, a triangular pyramid and a quadrangular pyramid. There are 10 stages in total. Figure 2 shows an example of this training.

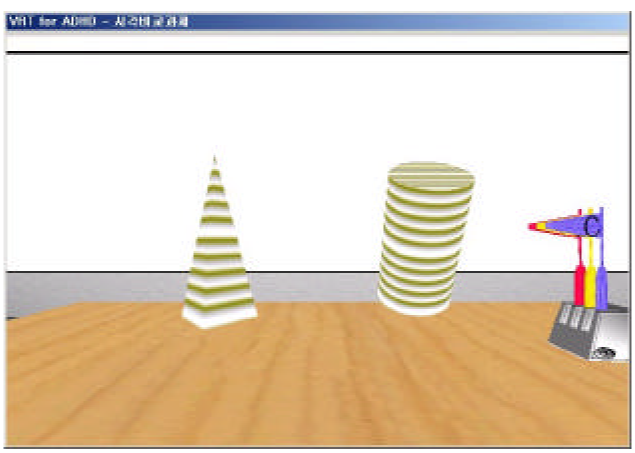

Figure 2. An example of VRCT

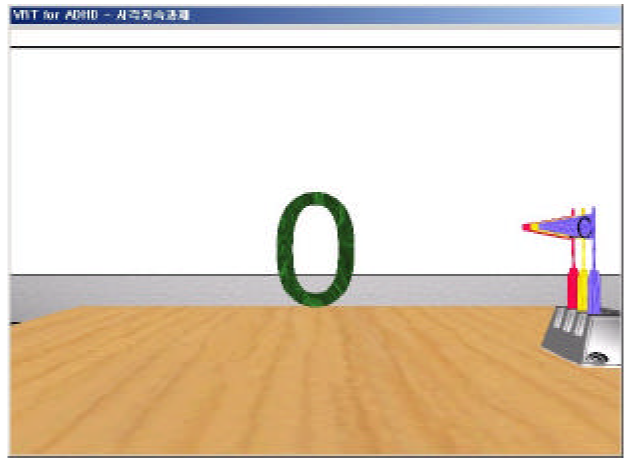

Figure 3. An example of VRST

As you can imagine from the title of this training, Virtual Reality Sustained Attention Training (VRST) is for enhancing sustained attention. In general, the procedure routine of VRST is similar to that of VRCT generally. If an operator starts the training, a subject can see an Arabic numeral on the desk (Fig. 3). The subject is encouraged to press the left mouse button when the number of '0' is presented after any number except when the number of '8' is presented. Otherwise, he or she is encouraged not to respond. The stage-completing procedure is the same as the one in VRCT. But, unlike VRCT, as the subject progresses to higher-level stages, the length of time that the stimuli (numerals) are presented increases gradually. Consequently the subject should have much more endurance and has to pay attention to the task continuously. In this training course, we also measure the number of correct answers and response times, just like in VRCT. There are also 10 stages in VRST.

2.3. EEG Biofeedback Training

Biofeedback subjects are connected to the EEG signal acquisition device using three electrodes attached to their scalp at the placement of Cz and grounded at the right and left ears. The sampling frequency of EEG signal acquisition is 256Hz. Before analyzing the EEG signal, we preprocessed it by Notch filtering and Lowpass Filtering. After that, the Fast Fourier Transform analyzes the latest 3-second data of acquired EEG signal in the frequency domain. And then we can extract frequency parameter such as Delta (0.5~3Hz), Theta (4~7Hz), Alpha (8~12Hz), SMR (12~15Hz), and Beta (15~18Hz). The data is updated every 0.5 second and we can measure frequency parameter in real time. Each frequency parameter is displayed as a bar graph in the EEG analyzing program, and then the operator can control the threshold levels of the parameters (Fig. 4).

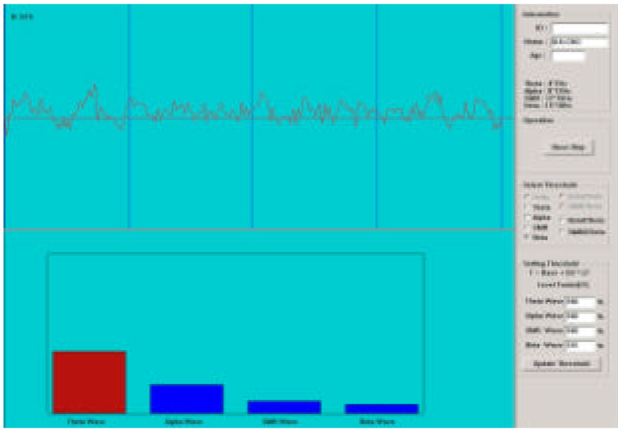

Figure 4. EEG Biofeedback Analysis Module for an operator

By controlling the threshold levels, the virtual environment is changed. In this pilot study, if the Beta wave is greater than the specified threshold level, the change as positive reinforcement is created in the virtual environment.

Before every training session, we measure the subject's base line of EEG because that may be different according to emotional or physical conditions. If the subject who is wearing an HMD with attached EEG electrodes pays attention to the VE, the Beta wave goes over the specified threshold, and the score increases and the VE is changed. When the subject isn't able to be attentive and the score makes no changes, the operator encourages the subject to be more attentive or lower the threshold level.

As the score progresses, a dinosaur egg rises from the desk. Then the egg is splits into two pieces. From the broken egg, one part of a dinosaur picture appears from the whiteboard gradually. If the score reaches '100' and all six parts of the picture are put together, the subject can hear the dinosaur's roaring (Fig. 5). The completion times are measured.

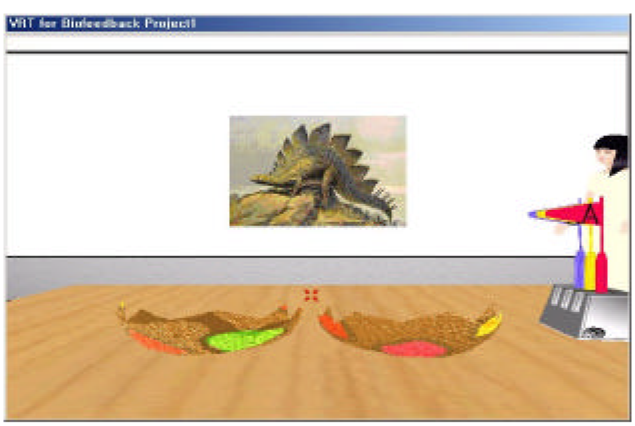

Figure 5. An example of EEG Biofeedback training : a completed scene

2.4. Hardware and Software Configurations

We used 800x600 HMD (virtual image size is 44-inch at 2m and viewing angle is 62 degree diagonal) and InterTrax II head tracker that has 3 DOF (Degree of Freedom). In biofeedback training, a 4-channel EEG signal acquisition device (LAXTHA Inc.) and two computers that have a Pentium III 500Mhz CPU, 256MB of RAM and a graphic acceleration card.

Virtual environments are designed using Rhinoceros (Robert McNeel & Assoc.) and 3D Studio Max (Kinetix). For the real time rendering, we used Visual C++ 6.0 and DirectX 7.0a SDK (Software Development Kit). In all of the training scenarios, the frame rate was over 60, so we had no trouble in the real time virtual environment.

3. Experiments

50 subjects, aged 14 to 18, who had committed crimes and had been isolated in a reformatory, took part in this study. They had some difficulty in learning in school and they were inattentive, impulsive, hyperactive and distracted. Although they were not officially diagnosed as ADHD, about 30% of them most likely had ADHD. They were randomly assigned to one of five 10-subject groups: a control Group, two placebo groups, and two experimental groups. Each group consisted of 10 subjects, respectively (Table 2). The experimental groups and the placebo groups underwent 8 sessions over two weeks, which were about 20 minutes in length. The control group underwent no training session during the same period of time.

Table 2. Training groups

Group	Training task	Number of subjects
Control Group	Waiting	10
Placebo Group 1	Desk-Top VR EEG Biofeedback Training (DVRBT)	10
Placebo Group 2	Desk-Top VR Cognitive Training (DVRCT)	10
Experimental Group 1	Virtual Reality EEG Biofeedback Training (VRBT)	10
Experimental Group 2	Virtual Reality Cognitive Training (VRCT)	10

Our hypothesis is that Virtual Reality is helpful for attention. And we also posit that VR-EEG Biofeedback training and our cognitive training courses also supports attention enhancement. That is why we divided the subjects into five groups. Therefore, the Placebo groups were for proving the efficacy of VR. While the experimental groups used a HMD and Head Tracker in each session, the placebo groups used only a computer monitor. Consequently, only the experimental Groups could look around the virtual classroom. Besides that, Placebo Group 1 and Experimental Group 1 performed the same task (EEG Biofeedback Training), and Placebo Group 2 and Experimental Group 2 also performed the same task (Cognitive Training). For Cognitive Training groups, Virtual Reality Concentration Training was offered in odd sessions and Virtual Reality Sustained Attention Training in even sessions.

Before each training session, all subjects were first trained to become accustomed to the virtual environment as a warm-up. All subjects performed a Continuous Performance Task (CPT) before and after all training sessions.

4. Results

Mean pre- and post-training CPT scores and the standard deviation of each score are presented in Table 3. The repeated measure MANOVA test was used to evaluate the effect of AES.

The number of correct answers, omission errors and response sensitivity (d') for experimental groups shows significant improvement ($p<0.01$) while control group indicates no significant change. Hence Inattentiveness of the experimental groups became reduced and they were supposed to be consistently attentive. The commission errors and response times were also reduced to a small degree but those were not significant.

Table 3. Mean CPT scores of subjects. Ex. means Experimental group, Pl. means Placebo group, and Con. means Control group. Standard deviation of the scores in parentheses.

	Ex. 1	**Ex. 2**	**Pl. 1**	**Pl. 2**	**Con.**
The number of correct answers					
Pre	310.38(6.93)	310.78(5.02)	312.00(6.14)	312.50(5.28)	314.78(5.47)
Post	319.75(2.92)	320.44(2.60)	316.44(2.83)	316.90(5.59)	315.44(4.45)
The number of omission errors					
Pre	13.63(6.93)	13.22(5.02)	12.00(6.14)	10.50(5.87)	9.22(5.47)
Post	4.25(2.92)	3.67(2.60)	7.56(2.83)	7.10(5.59)	8.56(4.45)
The number of commission errors					
Pre	23.13(4.91)	19.44(7.67)	19.11(7.17)	17.10(9.97)	19.11(7.77)
Post	17.00(7.65)	12.67(10.33)	13.56(5.73)	16.30(11.12)	15.11(10.47)
Reaction time (T score)					
Pre	48.37(12.35)	54.52(15.72)	53.85(13.96)	49.50(14.32)	52.77(17.89)
Post	40.84(12.86)	38.62(19.80)	47.10(11.95)	48.85(17.30)	47.16(22.88)
Response sensitivity (Attentiveness, T score)					
Pre	57.33(7.73)	55.35(8.30)	55.60(6.02)	55.62(10.52)	53.33(5.52)
Post	49.28(9.49)	41.83(7.70)	51.44(4.49)	49.77(17.19)	50.52(10.77)

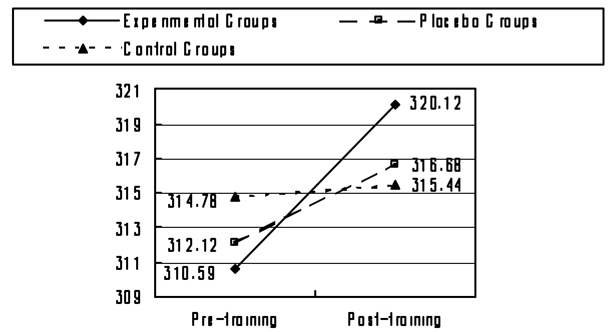

Figure 6.The mean number of correct answers in CPT.

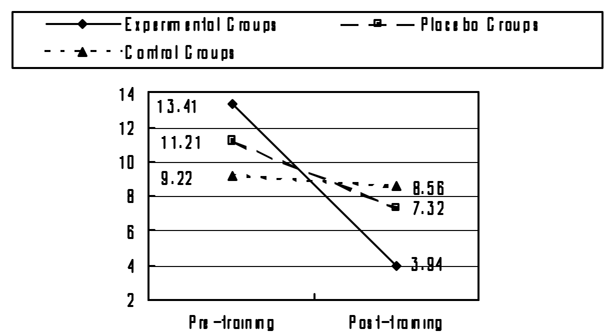

Figure 7. The mean number of omission errors in CPT.

Lastly, the Virtual Reality EEG Biofeedback training group and the Virtual Reality Cognitive training group show no significant difference.

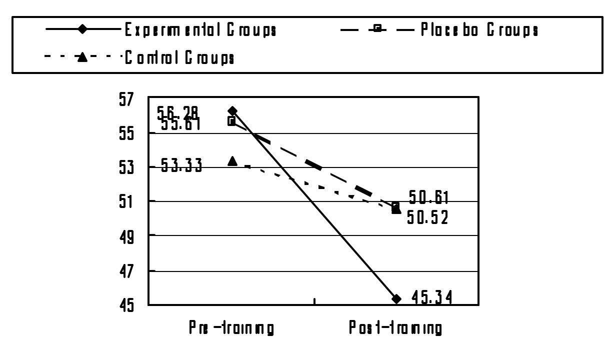

Figure 8. The mean response sensitivity in CPT.

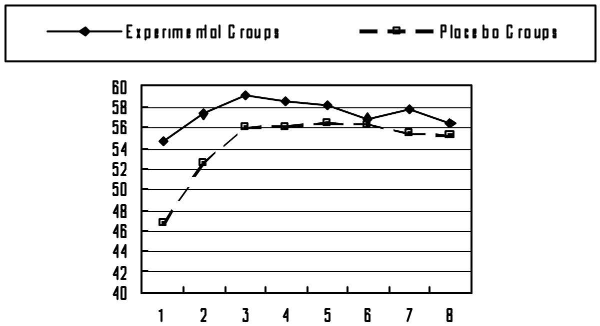

Figure 9. The mean number of correct answers in VRCT.

In addition, the experimental groups show significant differences ($p<0.01$) with the placebo groups in the same score. This means that immersive VR is more helpful for attention training than Desk-top VR (Figure 6, 7, 8).

Figures 9 and 10 represents the mean number of correct answers in each cognitive training session. In figure 11, the mean completion time for VR EEG Biofeedback training is illustrated. For those figures, the experimental groups are slightly superior to the placebo groups but it is not significant.

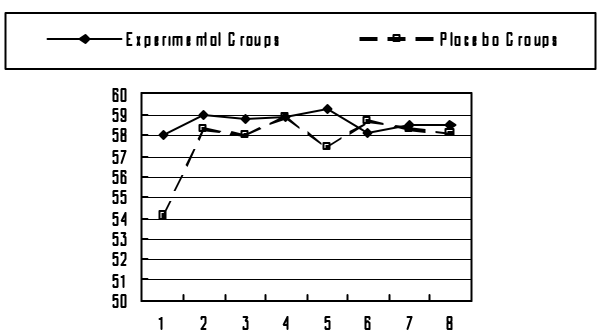

Figure 10. The mean number of correct answers in VRST.

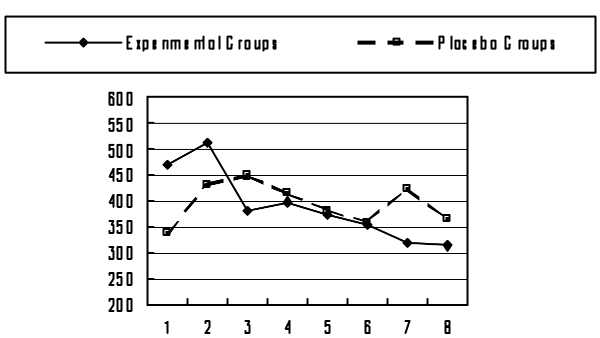

Figure 11. The mean completion time in VR EEG Biofeedback training.

5. Conclusions

We developed the prototype of the Attention Enhancement System using Virtual Reality technology and EEG biofeedback. According to our clinical test with that, we can conclude that our system possesses the ability to improve the attention span of children and adolescents with behavioral problems and help them learn to focus on some tasks.

Immersive VR may be appropriate for attention enhancement. For some subjects, they said that training only with a monitor, that is desktop VR, was tedious and uncomfortable. But with a HMD, they were motivated rather than bored. Then, VR based EEG Biofeedback training is also applicable to that. In a certain aspect, EEG Biofeedback training is tiresome and difficult for children and adolescent. The immersive Virtual Reality can supplement the training and keeping it interesting.

In our results, we found that both VR EEG Biofeedback and VR cognitive training has great effect for attention enhancement.

Our subjects had some social and behavioral problems but they were not diagnosed as ADHD officially. Therefore we will apply our system to ADHD diagnosed children in order to prove the possibility of ADHD treatment. Out another hypothesis is that the combination of Virtual Reality, EEG Biofeedback, cognitive training and psychostimulant medication for intensive ADHD treatment.

In fact, we have developed another cognitive training for alternating attention and divided attention. However it was very difficult for the subjects to understand as well as complete.

Although we used only Beta wave as a feedback control on EEG Biofeedback, we made impressive results. But in the near future, we will use another protocol such as Beta/Theta feedback control, make up for the weak points of our training contents and improve the graphic quality of VR.

6. Acknowlegement

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