Psychology Science Quarterly, Volume 50, 2008 (2), pp. 259-268

The relationship between EEG band power, cognitive processing and intelligence in school-age children[1]

TONGRAN LIU[2,3], JIANNONG SHI[2], DAHENG ZHAO[4] & JIE YANG[5]

intellectually average children as the control group from a regular class were selected in the present study and the main neural mechanism pertaining to high intelligence was investigated. The electroencephalogram (EEG) was recorded and the relationship between different percentages of Delta, Theta, Alpha1, Alpha2, Beta1 and Beta2 and intelligence and cognitive ability were analyzed. The results suggested that Delta power activity in brighter individuals was more than that in normal individuals, and Alpha2 and Beta1 power activity in higher intelligence individuals were less than that in normal individuals. In high ability group, Alpha1 was significantly correlated with visual search ability, and Theta band correlated with simple abstract matching significantly. While in the normal group, Delta band related significantly with short term memory abilities. Spectral EEG parameters could be regarded as neural bases for fast reaction and a good tool to discriminate high intelligent children from the average.

Key words: Event-related potential; EEG band power; Intelligence; Cognitive processing, gifted children

[1] Sponsorship: This research was supported by National Natural Science Foundation of China Grant (No. 30670716) and Key Project of Knowledge Innovation Engineering of Chinese Academy of Sciences (No. KFSHZ2007-10).

[2] Jiannong Shi, Division of Developmental and Educational Psychology, Chinese Academy of Sciences, 10A Datun Road, Chaoyang District, 100101 Beijing, PR China. Phone: + 86 10 64855744, fax: + 86 10 64872070, email: shijn@psych.ac.cn

[3] Division of Developmental and Educational Psychology, Chinese Academy of Sciences

[4] Beijing No.8 Middle School

[5] Beijing Yihai Primary School, Beijing, PR China

Introduction

High ability individuals are always regarded as people who have fast brains (Chalke and Ertl, 1965), and they react much faster than normal ones in cognitive tasks (Kyllonen, and Christal, 1990), but to find the basic neural mechanism for high intelligence is a troublesome question (Deary and Caryl, 1993). It is extensively and successfully accepted that event-related potentials (ERPs) can record fast brain dynamics during cognitive processes in human brains (Hillyard, Mangun, Woldorff and Luck, 1995; Rugg and Coles, 1995). In the electroencephalogram (EEG) studies, some studies pertaining to intelligence were concentrated on time domain (Fjell and Walhovd, 2001; Houlihan, Stelmack and Campbell, 1998; Jaušovec and Jaušovec, 2000b, 2001; Walhovd and Fjell, 2001, 2002), and some were on frequency domain (Doppelmayr, Klimesch, Stadler, Pöllhuber and Heine, 2002; Gevins and Smith, 2000; Jaušovec, 2000; Jaušovec and Jaušovec, 2004; Schmid, Tirsch, and Scherb, 2002). EEG studies concentrating on time domain offered a real time record of information processing between the presentation of a stimulus and a behavioral response, and they mostly contributed to the values of two parameters: latency and amplitude. It is found that highly intelligent individuals have more regular ERP waveforms and they showed shorter P300 latencies and larger amplitudes than their normal peers do (Jaušovec and Jaušovec, 2000b). In the frequency domain studies, alpha, beta, theta and delta power are employed as important parameters to represent the neural activities and processing mechanisms. It is presented that upper Alpha correlates with semantic processing ability, while lower-1 Alpha and lower-2 Alpha relate to devoted attention source that encoding novel signals (Doppelmayr et al., 2002).

Some previous studies have explored the relationship between cognitive processing and ERPs (Doppelmayr, Klimesch, Sauseng, Hödlmoser, Stadler and Hanslmayr, 2005; Houlihan, Stelmack and Campbell, 1998; Taylor and Smith, 1995). Houlihan et al. (1998) reported that there were weak negative correlations between P300 amplitude and the memory set, and P300 amplitude to the probe stimulus decreased with increases in memory set load. P300 latency was regarded as the indicator of the information processing speed. Their data presented that brighter individuals had longer P300 latency in the memory task than average individuals, and the results brought up some doubtable questions about the relationship between pure processing speed, P300 latency and intelligence. There are also some studies concentrating on the relationship between cognitive behavior performance and EEG band power (Jaušovec and Jaušovec, 2000a, 2004; Neubauer, Fink and Schrausser, 2002; Neubauer and Fink, 2003; Neubauer, Grabner, Freudenthaler, Beckmann and Guthke, 2004), but the results and conclusions are not consistent with each other. Doppelmayr et al. (2005) reported that high ability individuals had significantly larger Theta activity than average individuals, and the upper Alpha band (10-12 Hz) had a significant interaction with the difficulty of cognitive tasks. However in some complex cognitive tasks such as working memory tasks and figural learning tasks, it is reported that only Theta band induces desynchronization/synchronization (ERD/ERS) in working memory tasks and Alpha band has significant relations with learning tasks (Jaušovec and Jaušovec, 2004).

Some studies focusing on developmental changes explored the relationship between time domain parameters and cognitive performance on school-age children (Taylor and Smith, 1995), and their findings suggested that cognitive performance had negative correlation with latency and positive correlation with amplitude. Gevins and Smith (2000) employed a spatial memory task but did not find any significant relations between Theta and Alpha power and cognitive performance in school-age children. It is assumed that these divergent findings are due to the different difficulty of the cognitive tasks (Doppelmayr et al., 2005).

Time domain studies presented some neural evidents for processing speed, that is, supportive neural network for fast reaction. But these results still did not explain why brighter individuals had the faster neural network systems. In other words these results still could not well explain the neurobiological origin composing these faster neural action systems. While it is well known that EEG band power are comprised of Alpha, Beta, Delta, Theta et al. bands, and the percentages of these bands are different individually. In the present study we wanted to explore the relations between percentages of these bands and cognitive ability, and we regarded these different percentages of different bands as the basic neural bases for the different neural network systems. Another goal of the present study was to determine neural bases for high intelligence on school-age children. To this end, we measured six kinds of EEG band power: Delta (0.5-4Hz), Theta (4-8Hz), Alpha1 (8-11Hz), Alpha2 (11-14Hz), Beta1 (14-25Hz) and Beta2 (25-35Hz), and basic cognitive abilities through attention, memory and matching tasks.

Experiment1

Materials and methods

Participants

Forty-seven participants were selected for the present study. The entire sample consisted of two groups: (1) an intellectually gifted group [*n*=24, 14 boys and 10 girls; ages ranged from 10.8 to 12.4 years (mean age =11.2)]; and (2) an intellectually average group [*n*=23, 12 boys and 11 girls; ages between 11.1 to 12.2 years (mean age =11.3)]. The highly intelligent children were recruited from an experimental gifted class of a middle school in Beijing, and they were identified and selected from about 1500 candidates by using multiple criteria and multiple methods. Children's intelligence test scores and achievement scores (mainly for Chinese, English and mathematics) were above the 95th percentile. There were several steps for the identification of these gifted children: application, primary screening test (Standford-Binet Intelligence Test (revised) and Wechsler Preschool and Primary Scale of Intelligence (revised) were used), retest (Five main criteria were considered: cognition, creativity, learning ability, special talent, personality traits), further confirmation (More information about the children's personality traits and physical conditions were gathered), identifying through practice (Further identification through practice (student's learning process) was emphasized in this step. To educate them in equal conditions and environment and investigate their potential and actual performance levels was continuation of the identification procedure) (Shi and Zha, 2000). The average children were from among those who responded to an advertisement placed in a primary school in Beijing.

Before the electroencephalogram (EEG) recording, all participants were tested by Cattell's Culture Fair Test (CCFT, children's edition) (Cattell & Cattell, 1960) and Test of Nonverbal Intelligence (TONI-2, a Language-Free Measure of Cognitive Ability, Picture Book Form A) (Brown, Sherbenou and Johnsen, 1982; Wu, Hu and Lin et al. revised, 1990). IQ for the high ability group was 123.4, and IQ for the normal group was 97.9. All children with normal or corrected-to-normal vision were free from neurological or psychiatric problems, and all were right-handed and were naïve to electrophysiological procedures. Informed consent was obtained from all teachers and parents of the children.

Procedure

During the electrophysiologic acquisition period, participants sat comfortably in a reclining chair within an electrically shielded, sound-attenuated booth and watched self-chosen soundless videos. All participants were instructed to sit as quietly as possible. None of the subjects experienced difficulty complying with this instruction. The duration of the test session was approximately 10 min.

EEG recording and data analysis

Nose-referenced EEG (amplified by SynAmps 2 at DC 40 Hz, sampling rate 1000 Hz) was recorded with Ag-AgCl electrodes attached to the scalp sites F3-Fz-F4 (frontal: left-central-right, respectively), C3-Cz-C4 (central: left-central-right, respectively), P3-Pz-P4 (parietal: left-central-right, respectively), and Oz (occipital central), according to the International 10-20 system (Jasper, 1958). Two active electrodes were placed at the right and left mastoids. Eye movements were monitored with electrodes attached below and at the lateral corner of the right eye. EEG recording of 10 min was segmented in 300 epochs with a length of 2000 ms each. These epochs were carefully checked for artifacts with very strict criterion in order to make remaining epochs not associate with any small changes in horizontal and vertical eye movements and muscle artifacts.

Results

Table 1:
Mean percentages of Delta, Theta, Alpha1, Alpha2, Beta1 and Beta2 in both groups

Groups	Delta	Theta	Alpha1	Alpha2	Beta1	Beta2
Normal	41.92	15.59	7.77	5.55	15.88	13.29
	(7.90)	(1.56)	(1.71)	(0.94)	(3.33)	(4.20)
Supernormal	36.68	15.08	8.34	6.68	18.21	14.89
	(4.71)	(1.27)	(1.69)	(1.58)	(2.20)	(2.24)

Note: figures in parentheses are standard deviations in this table and the following tables.

The results of *t*-Test showed that individuals with higher intelligence had less Delta band activity (Group effect $t(1, 44)=2.757$, $P=0.008$), and more Alpha2 and Beta1 activities than the normal children (Alpha2: Group effect $t(1, 44)=-2.906$, $P=0.006$; Beta1: Group effect $t(1, 44)=-2.821$, $P=0.007$).

Experiment 2

Materials and methods

Participants

The same participants in Experiment 1 participated in Experiment 2.

Procedure

Two groups of participants were instructed to finished four simple cognitive tasks to explore their abilities on Visual search, Short term memory, Simple and Complex abstract matching.

Visual search task: Experimental stimuli were presented in central vision on a black background that subtended approximately 1.5°×3.4°. Each type of stimulus consisted of a single probe-like Arabic number (or English letter or Chinese words) on the upper part of the screen and another string of four Arabic number (or English letters or Chinese words) on the nether part. All Arabic numbers and English letters were presented by using a 'Times New Roman' font, and Chinese words were in a 'Song' font. Half of the trails had the target stimulus in the Arabic numbers string (or English letter or Chinese words), and for the other half, there was not target stimulus in the string. Participants were instructed to judge whether the target stimuli were among the distractors and they had to finish 20 practice trials and 120 trials for each experimental condition. Instructions stressed speed and accuracy.

Short term memory task: The task revised Sternberg (1966). Ten Arabic numbers (0-9) were used as stimuli in this short term memory task, and participants were firstly instructed to see a random series of one to six different numbers for 1200 ms each number and the series varied at random from trial to trial. Then a warning signal came after a 2000 ms delay, and the test item displayed, and participants were asked to judge whether this test item was in the previous series. Positive and negative responses were required with equal frequency. There were 24 practice trials and 144 test trials for each participant who was instructed to respond as both rapidly and correctly as possible.

Simple Abstract matching and Complex abstract matching tasks: We revised the research paradigm of Hoyer, Rebock and Sved (1979). There was a frame in a white background in the center, and there were three blocks in each frame (two at the top and one at the bottom). Each block was composed by three factors: shape (triangle, cross, rotundity), amount (2,3,4) and orientation (horizontal, vertical and declining), and participants were asked to judge the similarity of the blocks at the top and the ones at the bottom and their judgment criterions were based on these three factors. If participants judged that the left one at the top had more similarity with the bottom one, they were instructed to press 'Z' button as rapidly as possible. If they judged that the right one at the top had more similarity with the bottom one, they should press 'M' button as rapidly as possible. There were two levels of difficulty in the abstract matching tasks, and simple abstract matching task had one of the three factors fixed with the other two changed randomly, and complex abstract matching task had all the three factors changed randomly. There were 10 trials for practice, and 36 trials for test (including

18 trials for simple abstract matching tasks and 18 trials for complex abstract matching tasks). The 'Z' button and 'M' button responses were designed with equal frequency.

Results

Table 2:
Mean reaction time for Visual search, Short term memory, Simple and Complex abstract match in both groups

Groups	Visual search	Short term memory	Simple abstract matching	Complex abstract matching
Normal	1099.24 (121.13)	1604.02 (354.55)	2101.18 (407.61)	2692.82 (365.31)
Supernormal	878.91 (130.99)	1229.31 (282.57)	1432.79 (374.61)	1800.71 (428.23)

The results of *t*-tests presented that the highly intelligent group had significant faster reaction speed than the normal group on all tasks (Visual search: $t(1,44)=5.907$, $P=<0.001$; Short term memory: $t(1,44)=3.980$, $P<0.001$; Simple abstract match: $t(1,44)=5.796$, $P=<0.001$; Complex abstract match: $t(1,44)=7.567$, $P=<0.001$).

Table 3:
Correlation of EEG band power percentages and reaction time of four cognitive tasks for all children

	Delta	Theta	Alpha1	Alpha2	Beta1	Beta2	VS	STM	SAM	CAM
Delta	1									
Theta	0.38**	1								
Alpha1	-0.44**	-0.19	1							
Alpha2	-0.51**	-0.31**	0.53**	1						
Beta1	-0.76**	-0.52**	0.33**	0.44**	1					
Beta2	-0.62**	-0.36**	0.13	0.23**	0.61**	1				
VS	0.20	0.02	-0.16	-0.18	**-0.21***	-0.14	1			
STM	**0.24***	**0.22***	-0.06	-0.16	**-0.25***	**-0.23***	0.42**	1		
SAM	0.14	0.19	-0.10	-0.14	-0.15	-0.17	0.41**	0.33**	1	
CAM	0.18	0.19	-0.11	-0.17	-0.19	**-0.21***	0.46**	0.41**	0.71**	1

Note: VS= Visual search; STM=Short term memory; SAM= Simple abstract matching; CAM= Complex abstract matching;
** presents that the correlation is significant at the 0.01 level;
* presents that the correlation is significant at the 0.05 level

Both Delta and Theta had significant positive correlations with Short term memory (Delta: *P*=0.019; Theta: *P*=0.028). Beta1 has significant negative correlations with Visual search (*P*=0.045) and Short term memory (*P*=0.014), and Beta2 correlated with short term memory and complex abstract matching significantly (for short term memory *P*=0.025; for complex abstract matching *P*=0.04).

Table 4:

Correlation of EEG band percentages and reaction time of cognitive tasks for the two groups

Group	Tasks	Delta	Theta	Alpha1	Alpha2	Beta1	Beta2
Supernormal	VS	0.15	0.12	**-0.39****	-0.21	-0.07	0.07
	STM	-0.03	0.11	0.00	-0.08	-0.02	-0.02
	SAM	0.13	**0.34***	-0.06	-0.00	-0.15	-0.11
	CAM	0.01	0.22	-0.04	0.00	-0.04	-0.06
Normal	VS	-0.02	-0.16	0.20	0.17	-0.07	-0.01
	STM	**0.32***	0.26	-0.06	0.11	0.28	0.23
	SAM	-0.17	0.09	0.10	0.13	0.15	0.01
	CAM	0.00	0.21	0.03	0.08	-0.00	-0.09

Note: VS= Visual search; STM=Short term memory; SAM= Simple abstract matching; CAM= Complex abstract matching;
** presents that the correlation is significant at the 0.01 level;
* presents that the correlation is significant at the 0.05 level

In high ability group, Alpha1 correlated significantly with Visual search (R=-0.39, *P*=0.007), while Theta related with Simple abstract matching significantly (R=0.34, *P*=0.02). While in the normal group, Delta correlated significantly with Short term memory (R=0.32, *P*=0.04).

Discussion

From the results of EEG data, brighter individuals had fewer Delta, more Alpha2, more Beta1 activities than normal individuals did. From the results of cognitive tasks, brighter group had shorter reaction time than normal group in all of the four cognitive tasks. The correlations of EEG data and cognitive ability for both groups presented that the Delta, Theta, Beta1 and Beta2 had significant positive correlations with children's abilities on Short term memory, and Beta2 also had significant positive correlations with children's complex abstract matching performance. Considering the two groups separately, in high ability group, Alpha1 was negatively correlated with visual search ability and Theta positively with simple abstract matching, while in the normal group, Delta band was significantly related with short term memory abilities.

Our results supported that Delta power activity decreased (Schmid, Tirsch, and Scherb, 2002) when IQ increased, and Alpha band (7.5-12.5 Hz) increased when IQ decreased (Schmid, Tirsch and Reitmeir, 1997; Schmid, Tirsch and Scherb, 2002). In Schmid et al.

(2002) research, they used WISC-R test and counted the correlations between its 11 subtests variables with EEG bands. Their results also suggested that Alpha power positively correlated with the intelligence variables, while some lower frequency bands had negative correlations with intelligence subtests. Schmid et al. (2002) used participants' performances in their study while we used participants' reaction time in the present study, so our results of Delta, Theta and Alpha1 bands mostly supported their results, but it still had some differences in Beta band activity. Schmind, Tirsch and Scherb (2002) interpreted the correlation between Alpha power and intelligence as the maturation of brain which was expressed by the increasing number of synapses and ability of controlling intracerebral neural network system, and individuals with high intelligence might have high degree of maturation in brain structure and synapses action systems (Schmind, Tirsch and Scherb, 2002).

According to previous studies, learning, memory and problem solving were regarded to have close relations with intelligence (Demetriou, Christou, Spanoudis, and Platsidou, 2002; Doppelmayr et al., 2002; Gevins and Smith, 2000; Jaušovec and Jaušovec, 2004), but the results from these studies were inconsistent. It is reported that Theta (4-6Hz) power had close relationship with episodic memory processes and working memory performance (Klimesch, 1996), while upper Alpha (10-12 Hz) power correlates with semantic memory ability (Klimesch, 1997), and lower-1 and lower-2 Alpha (6-10 Hz) are related to attention (Klimesch, 1999). Complex cognitive processing needs more complex neural networks and more neural source to make sure that all the processing can be performed well with fast speed, so different kinds of systems, networks and parameters are mixed together. The four simple cognitive tasks employed in the present study were supposed to stand for the basic cognitive ability and neural actions.

There was some overlapping in our results, and we might draw that short term memory needs most complicated neural activities and it related with most kinds of band power in the neural system. While for high ability children, Alpha1 negatively correlated with visual search ability which presented the basic and simple attention ability, and it might suggest that this basic ability needed less neural source comparing to other cognitive abilities. Theta band had close relationship with simple abstract matching ability, but it did not had any significant correlations with other cognitive tasks, and it might suggest that Theta power controlled some medium complicated cognitive processing but not the most complicated processing.

It is supported that quantitative ERP changes in latency and amplitude attribute to changes in speed and capacity, while quantitative changes in ERP topography attribute to changes in implicated and/or strategy neural structures (Stauder, van der Molen and Molenaar, 2003). Using EEG parameters in frequency domain instead of latency and amplitude parameters in time domain can bring up new view points in the electrophysiologic studies. As it is known, EEG waves represent the summation of excitatory and inhibitory postsynaptic potentials (Eccles, 1973), and the different percentages of EEG band power might also closely relate to the effort of neural system, and even they might control the speed of neural transmission. The percentages of EEG power change with human development, and the efficiency of neural system and the speed of neural transmission may accelerate with human development as well.

In conclusion, the present findings confirmed significant correlations between different percentages of EEG power and intelligence and cognitive processing speed. According to the results, there seems to be more relationships between Delta, Alpha2 and Beta1 and intelligence. In the study of relationship between behavior response and EEG power, it is suggested that Delta, Theta, Alpha1 correlated significantly with basic cognitive abilities with different intelligent levels. These findings of EEG power may constitute an important factor to be taken into account in future research of finding the biological origin of individual differences in intelligence. Based on these findings, particular importance should be given to the use of spectral EEG frequency domain analysis as an additional tool for assessment of high ability individuals.

References

Brown, L., Sherbenou, R. J., & Johnsen, S. K. (1982). Wudian Wu, Zhifen Hu, and Xingtai Lin et al. revised (1990). Test of Nonverbal Intelligence: A Language-Free Measure of Cognitive Ability (TONI-2), Pro-ed, INC.

Cattell, R. B., & Cattell, A. K. S. (1960). *Handbook for the individual or group Culture Fair Intelligence Test.* Champaign, Illinois: Testing Inc.

Chalke, F., & Ertl, J. (1965). Evoked potentials and intelligence. *Life Sciences, 4*, 1319-1322.

Deary, I. J., & Caryl, P. G. (1993). Intelligence, EEG, and evoked potentials. In Vernon, P. A. (Ed.), *Biological approaches to the study of human intelligence* (pp. 259-316). Norwood, NJ: ABLEX.

Doppelmayr, M., Klimesch, W., Stadler, W., Pöllhuber, D., & Heine, C. (2002). EEG alpha power and intelligence. *Intelligence, 30*, 289-302.

Doppelmayr, M., Klimesch, W., Sauseng, P., Hödlmoser, K., Stadler, W., & Hanslmayr, S. (2005). Intelligence related differences in EEG-bandpower. *Neuroscience Letters, 381*, 309-313.

Eccles, J. C. (1973). *The understanding of the brain*. New York, NY: McGraw Hill.

Fjell, A. M., & Walhovd, K. B. (2001). P300 and neuropsychological tests as measures of aging: Scalp topography and cognitive changes. *Brain Topography, 14*, 25-40.

Gevins, A., & Smith, M. E. (2000). Neurophysiological measures of working memory and individual differences in cognitive ability and cognitive style. *Cerebral Cortex, 10*, 830-839.

Hillyard, S. A., Mangun, G. R., Woldorff, M. G., & Luck, S. J. (1995). Neural systems mediating selective attention. In M. S. Gazzaniga (Ed.), *The Cognitive Neurosciences* (pp.665-681). MIT Press, Cambridge, MA.

Houlihan, M., Stelmack, R., & Campbell, K. (1998). Intelligence and the effects of perceptual processing demands, task difficulty and processing speed on P300, reaction time and movement time. *Intelligence, 26*, 9-25.

Hoyer, W. J., Rebock, G. W., & Sved, S. M. (1979). Effects of varying irrelevant information on adult age differences in problems solving. *Journal of Gerontology; 34*, 553-560.

Jasper, H. H. (1958). The ten-twenty electrode placement system of the International Federation. *Electroencephalography and Clinical Neurophysiology, 10*, 371-375.

Jaušovec, N. (2000). Differences in cognitive processes between gifted, intelligent, creative, and average individuals while solving complex problems: a EEG study. *Intelligence, 28*, 213-237.

Jaušovec, N., & Jaušovec, K. (2000a). Differences in event-related and induced brain oscillations in the theta and alpha frequency bands related to human intelligence. *Neuroscience Letter, 293*, 191-194.

Jaušovec, N., & Jaušovec, K. (2000b). Correlations between ERP parameters and intelligence: A reconsideration. *Biological Psychology, 55*, 137-154.

Jaušovec, N., & Jaušovec, K. (2001). Differences in EEG current density related to intelligence. *Cognitive Brain Research, 12*, 55-60.

Jaušovec, N., & Jaušovec, K. (2004). Differences in induced brain activity during the performance of learning and working-memory tasks related to intelligence. *Brain and Cognition, 54*, 65-74.

Klimesch, W. (1996). Memory processes, brain oscillations and EEG synchronization. *International Jouranl of Psychophysiology, 24*, 61-100.

Klimesch, W. (1997). EEG-alpha rhythms and memory processes. *International Journal of Psychophysiology, 26*, 319-340.

Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis. *Brain Research Reviews, 29*, 169-195.

Kyllonen, P. C., & Christal, R. E. (1990). Reasoning ability is (little more than) working memory capacity?! *Intelligence, 14*, 389-433.

Neubauer, A. C., Fink, A., & Schrausser, D. G. (2002). Intelligence and neural efficiency: the influence of task content and sex on the brain-IQ relationship. *Intelligence, 30*, 515-536.

Neubauer, A. C., & Fink, A. (2003). Fluid intelligence and neural efficiency: effects of task complexity and sex. *Personality and Individual Differences, 35*, 811-827.

Neubauer, A. C., Grabner, R. H., Freudenthaler, H. H., Beckmann, J. F., & Guthke, J. (2004). Intelligence and individual differences in becoming neurally efficient. *Acta Psychologica, 116*, 55-74.

Rugg, M. D., & Coles, M. G. H. (Eds.) (1995). *Electrophysiology of Mind. Event-related Brain Potentials and Cognition*. Oxford University Press, Oxford.

Schmid, R. G., Tirsch, W. S., & Reitmeir, P. (1997). Correlation of developmental neurological findings with spectral analytical EEG evaluations in pre-school age children. *Electroencephalography and Clinical Neurophysiology, 103*, 516-527.

Schmid, R. G., Tirsch, W. S., & Scherb, H. (2002). Correlation between spectral EEG parameters and intelligence test variables in school-age children. *Clinical Neurophysiology, 113*, 1647-1656.

Shi, J., & Zha, Z. (2000). Psychological research on and education of gifted and talented children in China. In K. Heller, F. Moenks, R. Sternberg & R. Subotnik (eds.), *International handbook of research and development of giftedness and talent* (2nd ed.) (pp. 757-764). Amsterdam: Elsevier Science Ltd.

Stauder, J. E. A., van der Molen, M., & Molenaar, P. C. M. (2003). Age, intelligence, and event-related brain potentials during late childhood: A longitudinal study. *Intelligence, 31*, 257-274.

Sternberg, S. (1966). High-speed scanning in human memory. Science, 153, 652-654.

Taylor, M. J., & Smith, M. L. (1995). Age-related ERP changes in verbal and nonverbal memory tasks. *Journal of Psychophysiology, 9*, 283-297.

Walhovd, K. B., & Fjell, A. M. (2001). Two- and three-stimuli auditory oddball ERP tasks and neuropsychological measures in aging. *NeuroReport, 12*, 3149-3153.

Walhovd, K. B., & Fjell, A. M. (2002). The relationship between P3 and neuropsychological function in an adult life span sample. *Biological Psychology, 62*, 65-87.