The psychophysiology of selective attention and working memory in children with PPDNOS and/or ADHD

Gomarus, Henriette Karin

Publication date:
2010

Chapter 2

Cortical and autonomic correlates of visual selective attention in introverted and extraverted children

Monika Althaus, H. Karin Gomarus, Albertus A. Wijers, Lambertus J.M. Mulder, José L. van Velzen, Ruud B. Minderaa

The study described in this chapter has been published in the Journal of Psychophysiology,19:1, 35-49, 2005

Abstract

We investigated the performance on a selective attention task in two Groups of 8- to 12-year-old healthy children being characterized as extraverted and introverted, respectively. During task performance EEG-activity was recorded to investigate differential effects on a specific selection-related potential, the N2b. Cardiac activity was recorded continuously before, during and after task performance. Spectral energy was computed for three distinguishable frequency bands corresponding with a low (LF) mid- (MF) and high (HF) frequency component in heart rate variability (HRV). The extraverted children were found to show greater perceptual sensitivity in response to irrelevant information. They also exhibited a greater N2b-component while showing significantly greater decreases in, particularly, the LF- and MF-power of HRV during task performance as compared to baseline periods. The magnitude of the N2b and the task-related decreases in LF-power of HRV were found to correlate significantly with the degree of extraversion and task performance, as well as with each other. The findings are discussed in the light of how selective attention and changes in physiological state may be related to the children's temperament.
Key words: selective attention, introversion, extraversion, children, ERPs, autonomic responsiveness.

Introduction

In everyday life we are continuously exposed to many events occurring in our environment. Because of our limited information processing capacity these events cannot all be processed simultaneously to be perceived and consciously experienced by us. By orienting to only a small sample of the incoming information, we exclude most of the input reaching our peripheral receptor organs. This ability of the human information processing system, to process only that part of the information that may be relevant in a given situation, is commonly referred to as selective attention.

People differ in the way they are able to select relevant information from the vast number of stimuli they are exposed to. Introverted subjects have been suggested to have a narrower focus of attention than extraverted subjects (Stenberg et al., 1990). This narrower range of attention has been assumed to result in less extensive processing of stimuli that are not directly relevant to the primary task. Consequently, task-irrelevant or distracting information should be more easily ignored. This difference in selective processing has been explained by H.J. Eysenck's (1967) arousal theory of introversion-extraversion. According to this theory introverts are more easily aroused than extraverts with the consequence of reaching an *optimal* level of arousal more easily. The increased level of arousal in introverted people is supposed to lead to a narrower range of cue utilization and enhanced selective attention. Extraverts, on the other hand, should tend to *seek* stimulation in order to increase their level of arousal (Eysenck, 1981; Eysenck, 1982).

When arousal is low, attention is easily displaced leading to higher distractibility (Posner and Raichle, 1994). Under more demanding task conditions, however, the arousal level is supposed to increase. The introvert is then inclined to become over-aroused leading to a decrease in performance, whereas the extravert might reach a near to optimum level of arousal leading to improved performance. Better attentional performances are expected to be found in extraverts if processing demands are high, habituation to the task is low, and inter-stimulus intervals are short (Stenberg et al., 1990).

Prior to the study of differences in selective attention between children with externalizing and internalizing behavior problems, we investigated selective attention and its psychophysiological correlates in two groups of healthy, normally intelligent children who were judged to be introverted and extraverted, respectively. More specifically, the objective was to investigate the relationship between a specific selection-related potential in the EEG, changes in autonomic state, and the performance of a selective attention task in these two groups of children.

Theoretical background

Evidence for changes in arousal affecting selectivity, i.e. the efficiency of orienting to relevant inputs alone, has come from investigations into the interactions between the three distinguishable attention systems that have been postulated by Posner and colleagues (Posner, 1993; Posner and Petersen, 1990; Posner and Raichle, 1994; Turken and Swick, 1999; Webster and Ungerleider, 1998) as well as from studies on the participation of the locus coeruleus (LC) in cortically mediated attentional processes (Aston-Jones et al., 1999; Foote et al., 1991). Changes in activity of the locus coeruleus, this structure being described by Posner and colleagues to form an essential part of the vigilance system, have been suggested to contribute to the production of a behavioral state in which novel sensory stimuli are more effectively processed. This behavioral state has been postulated to be a necessary precondition for the elicitation of long latency, P3-like, event-related EEG potentials (Foote et al., 1991). In this context it is important to note that the authors of the LC studies pointed to the particular role of the peripheral *sympathetic* system, which should be activated in parallel with the central LC system (Aston-Jones et al., 1999).

Physiological Measures

Selectivity of attention in humans has previously been studied by using a visual attention task in which subjects have to attend to cued (relevant) information and ignore uncued (irrelevant) information (Posner, 1980). When measuring EEG, a difference has been observed between the ERPs evoked by, respectively, relevant and irrelevant stimuli. A stable ERP-component related to selective attention has turned out to be the N2b, a long latency *difference potential* reflecting a negativity when averaged responses to irrelevant stimuli are subtracted from averaged responses to relevant stimuli (Lange et al., 1998; Näätänen and Gaillard, 1983; Okita et al., 1985; Smid et al., 1999). This negativity appears between about 200-400 ms after the appearance of the stimulus to be attended to and reaches its maximum at centro-frontal positions. The N2b has been found in paradigms using several different selection features, e.g. color, location, or size. Hence, it appears to be unrelated to the type of selection cue (Wijers, 1989). Using a visual (color) selective attention paradigm in a developmental study comparing different age groups within the range of 7 to 24 years, Van der Stelt and colleagues (1998) could show that the N2b component had a later onset in children and young adolescents (7 to 15 year) while it also appeared to be more frontally distributed as compared to older adolescents and young adults who showed a more central distribution of this component. In general, the magnitude of the N2b has repeatedly been described as being related to both the difficulty of a discrimination task and the subject's efficiency in task performance (Kasai et al., 1999; Lorist et al., 1995; Mulder et al., 1989; Potts et al., 2002; Senkowski and Herrmann, 2002).

Measures of the individual's autonomic state and his autonomic responsiveness to an attention-demanding task can be derived from the cardiac signal. Spectral analysis of the fluctuations in inter-beat interval (IBI) times reveals three different components of heart rate variability (HRV) within three distinguishable frequency bands. The power of the various components is expected to be differentially affected by changes in parasympathetic and sympathetic activity. There is a high frequency (HF) component, which can be observed within a frequency band ranging from 0.15 to 0.40 Hz. This component corresponds to the individual's dominant respiration frequency and, thus, has been associated with respiratory sinus arrhytmia (RSA). Parasympathetic (vagal) autonomic activity has been assumed to be the major contributor to fluctuations in the high frequency band, and withdrawal of vagal activity has been shown to produce a decrease in the power of this component in particular (e.g. Akselrod et al., 1985; Grossman, 1992; Porges and Byrne, 1992).

A second component is found at about 0.10 Hz within a range from 0.07 to 0.14 Hz, called the mid-frequency (MF) band. This component is supposed to reflect the activity of the baroreflex, by means of which short term fluctuations in blood pressure are adjusted. Both, parasympathetically as well as sympathetically driven changes are supposed to modulate the power of HRV in the mid-frequency band (e.g. Mulder et al., 1995b; Pagani et al., 1992; Saul, 1990). Decreases of HRV in this band have been shown to be a sensitive index of the *amount* of mental effort invested in an attention-demanding task (e.g. Aasman et al., 1988; Althaus et al., 1998; Althaus et al., 1999; Redondo and Valle-Inclan, 1992).

A third component reflecting slower changes in heart rate is found within a low frequency (LF) band ranging from 0.02 to 0.06 Hz. Fluctuations in this range arise from vasomotor activity involved in the regulation of body temperature (Kitney, 1975) and renin-angiotensin system activity (Akselrod et al., 1985). Decreases in the power of this component have also been found in attention-demanding situations (Althaus et al., 1998; Jorna, 1992; Mulder, 1992). Changes in LF-power are also assumed to be affected by both, parasympathetically and sympathetically mediated changes in autonomic activity (e.g. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996).

Hypotheses

We investigated whether two groups of healthy, normally intelligent children who were judged to be introverted and extraverted, respectively, differ in (1) their way of performing a selective attention task, (2) their attention-related cortical responses to relevant vs. irrelevant information, and (3) their cardiac responsiveness to the task demands. To this end cardiac and EEG-activity was recorded from sixteen 8-to 12-year-old children while they performed a visual selective attention task. Heart rate was recorded continuously during two periods of rest preceding and following task performance, respectively, as well as during task performance. From the different types of errors made in response to relevant and irrelevant information we computed two types of parameters derived from signal detection theory (Green and Swets, 1966) reflecting the children's perceptual sensitivity (d') and their decision bias (β), respectively. Changes in perceptual sensitivity have previously been associated with phasic changes in the individual's level of arousal, while changes in decision criterion have been associated with changes in readiness to respond, this being dependent on the individual's tonic activation level (Broadbent, 1971; Sanders, 1983). The dependent measures of our comparisons, therefore, were, (1) d' and β in response to both relevant and irrelevant information as well as reaction times (RT) in response to relevant information, (2) the above-described N2b component as a cortical index of selective attention, while (3) autonomic responsiveness to the task demands was operationalized by computing rest-task differences (RTDs) in IBI times as well as in the spectral power of HRV obtained for the three frequency bands presented above.

Since our task was a highly demanding selective attention task with short inter-stimulus intervals, the following hypotheses were formulated according to what has been suggested by Stenberg and colleagues (1990). Extraverted children should be more selective, i.e. more efficient in ignoring irrelevant information. This should be reflected by a greater perceptual sensitivity and a smaller decision bias to especially irrelevant signals as well as by a greater N2b component at fronto-central positions. In contrast, the introverted children were expected to show a greater cardiac responsiveness to the task reflecting their propensity for becoming over-aroused during task performance, which is expected to accompany lower perceptual sensitivity and a greater response bias, particularly to irrelevant signals. This condition should be reflected by greater RTDs, especially in the power of LF and MF HRV, for power changes in these frequency bands are likely to be influenced by changes in both, parasympathetic and sympathetic activity, the latter, in particular, being associated with changes in arousal.

Methods

Participants

Sixteen healthy volunteers (eleven boys and six girls) ranging in age from 8 to 12 years participated in the study. Mean age (± *SD*) was 10.3 (± 1.2) years. All children performed in the range of normal intelligence. Mean Full Scale IQ (± *SD*) for the whole group was 108 (± 12).

Behavior assessment

Since a Dutch translation of Eysenck’s personality questionnaire for children was not available at the time of our experiment we used the *parent* version of a Dutch questionnaire that had originally been developed to assess children's social-emotional behavior as observed by their teachers (Groningen Behavior Checklist: School Situation, GBC-S) and further elaborated to assess the same type of behavior as observed at home (Groningen Behavior Checklist: Family Situation, GBC-F) (Kalverboer, 1973; Kalverboer, 1988; Schaefer et al., 1965). The GBC-F consists of 32 scales, each being represented by three items to be answered on a 4-points scale. By means of principal component analysis, five item clusters were identified and presumed to measure, respectively, Socially Negative, Socially Positive, Extraverted, and Introverted as well as Hyperactive-Impulsive behavior (Kalverboer, 1990). Based on samples of, respectively, n=1380 and n=130 primary school children, the scales could be shown to have high internal consistencies for the teacher version (Crohnbach's α ranging from .83 to .93) and moderate to high internal consistencies for the parent version (ranging from .71 to .91). The item clusters presumed to measure, respectively, introverted and extraverted behavior are presented in the appendix.

To measure the children's level of anxiety, possibly experienced shortly before task performance and/or more permanently, Spielberger's State-Trait Anxiety Inventory for Children (STAIC) was administered to the child before (20 state-items) and after (20 trait-items) task performance (Spielberger, 1973). The STAIC has been developed to measure anxiety in normal children within the age range of 8 to 15 years.

For making group comparisons between introverted and extraverted subjects we used the sum scores of the two item clusters corresponding with, respectively, the Introversion and Extraversion scale and constructed a single continuum score for Extra-/Introversion. To this end, first z-scores were computed separately for the Extraversion and Introversion scale. Subsequently, the standardized Introversion scores were subtracted from the standardized Extraversion scores resulting in a single Extra-/Introversion (E-I) score for each individual. The children with the eight highest scores ($z > 0$) were assigned to the extraverted group and the subjects having the eight lowest scores ($z < 0$) were assigned to the introverted group (see Table 1).

The two groups did not differ in Full Scale IQ or in age. Nor did they differ significantly in the degree to which they were reported to show Socially Negative, Socially Positive and Hyperactive-Impulsive behavior or with respect to the level of self-reported Trait and State Anxiety. Yet, we have to note that, although the group differences for Socially Positive behavior and State Anxiety did not reach statistical significance for rejecting the Null-hypothesis, their effect sizes for discriminating between the groups appeared to be moderate indicating that larger group sizes may lead to smaller p-values. Table 2 summarizes the various group statistics.

Table 1. Minimum, maximum, mean values and standard deviations of the Z-scores of Extraversion, Introversion and the sum of Extraversion minus Introversion presented for the whole group and the two subgroups of, respectively, extraverted and introverted children.

	Z-score Extraversion				Z-score Introversion				Z-score Extraversion minus Z-score Introversion (E-I)			
	Min	Max	M	SD	Min	Max	M	SD	Min	Max	M	SD
All (n=16)	-2.43	1.19	0	1	-1.31	1.8	0	1	-4.23	1.86	0	1.76
Extraverted (n=8)	-0.14	1.19	0.69	0.48	-1.31	0.24	-0.79	0.55	0.95	1.86	1.49	0.35
Introverted (n=8)	-2.43	0.43	-0.69	0.91	-0.02	1.8	0.79	0.63	-4.23	-0.33	-1.49	1.22

Table 2. Means, standard deviations, F-values, significance, effect sizes in terms of Cohen's d and η^2 as well as the power observed (1-β) for group differences in the various measures used to characterize the groups.

	Extraverted (n=8)		Introverted (n=8)						
	M	SD	M	SD	F (1,14)	p	d	η^2	1-ß
Extraversion	40.4	2.5	33.1	4.8	15.95	.002	1.91	.55	.96
Introversion	16	2.2	22.1	2.4	27.04	.000	2.65	.68	.99
E-I	1.49	0.35	-1.49	1.22	120.09	.000	3.32	.90	1.00
Full Scale IQ	108	11	107	14		n.s.			
Age (in years)	10.3	1	10.3	1.4		n.s.			
Socially Pos	35.5	7.9	30.9	4.9	1.82	n.s.	0.70	.12	.24
Socially Neg	26.1	8.6	26	6.9		n.s			
Hyperactive	25.1	7.5	24.5	6.1		n.s.			
Trait Anxiety	5.7	2.9	6.6	2.3		n.s.			
State Anxiety	6.4	3.4	8.6	1	2.61	n.s.	0.88	.17	.32

Note that the effect size Cohen's d is small for $d \leq 0.5$; moderate for $0.5 < d < 0.8$; and high for $d \geq 0.8$.

Task and Procedure

Task

The task was a visual selective attention task derived from Posner's paradigm of visual orienting (Posner, 1980). It consisted of 600 trials each starting with a fixation frame (see Figure 1). This frame contained a central fixation cross, flanked by a red rectangle on one side and a blue rectangle on the other side. The rectangles were displayed throughout the task. The position of the colored rectangles (blue at the right and red at the left of fixation or the other way around) was balanced over the subjects. After a short delay varying from 750 to 900 ms the fixation cross was replaced by a cue consisting of a small central red or blue square indicating whether the red or the blue rectangle had to be attended to. After another 800 ms a letter ("T", "V" or "O") appeared in one of the rectangles. The subject was instructed to respond by pressing the button *only* if the target "T" appeared in the cued rectangle as indicated by the colored square. The letter was presented during 150 ms followed by a 700 ms frame showing the empty rectangles and the cue. During this period the subject was allowed to respond.

There were eight stimulus conditions determined by the stimulus being either a target letter or a non-target letter, being relevant (validly cued) or irrelevant (invalidly cued), and by the direction of attention (cued left vs. cued right). Each stimulus condition was randomly presented to the subject and appeared equally often (75 times). Hence, in 25% of the trials a response was required.

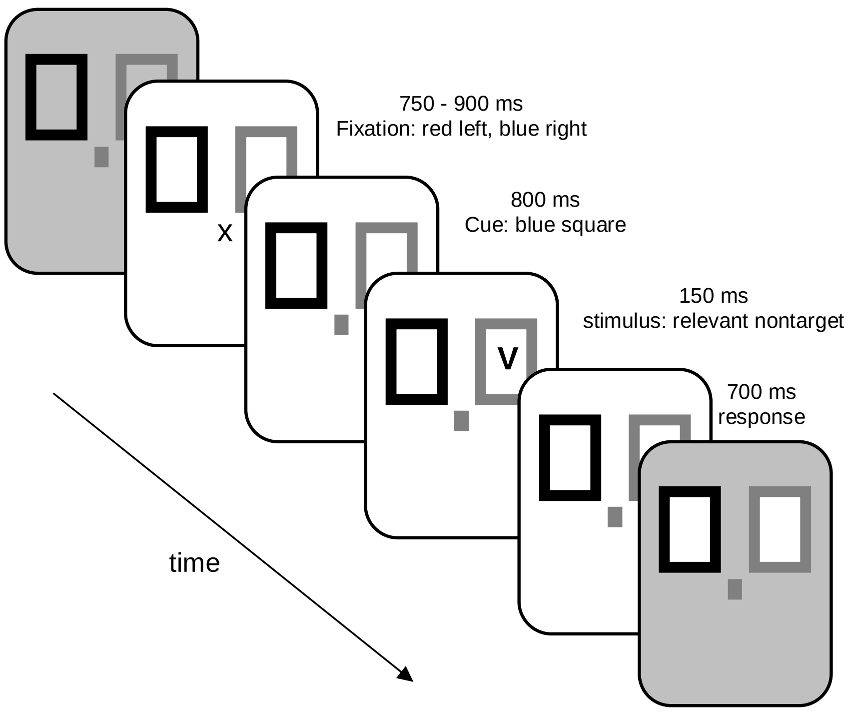


Figure 1. Stimulus presentation and timing, an example of a relevant non-target trial (T was the target letter among the randomly occurring letters V, O and T).

Procedure

After a brief introduction and practicing all types of task conditions in a random sample of 24 trials, the electrodes were placed. Before starting the experimental task the child practiced another 60 trials. The child was asked to fixate at the center of the screen, to blink as little as possible and to respond fast but accurately. The experiment was divided into six blocks, each containing 100 trials. Between the blocks, short periods of rest (40 seconds) were given in order to allow the child to move his eyes away from the screen and to stretch his limbs. Moreover, before and after performing the task the child was asked to sit still and relax with his eyes closed, both times for a period of 4 minutes. During these periods baseline measures of cardiac activity were obtained.

Recording of the physiological signals

EEG

Electroencephalographic activity was recorded from electrodes placed on the midline of the scalp (Fz, Cz, Oz) and at parietal sites (P3, P4, P7, P8) according to the 10-20 system (Jasper, 1958). The electrodes were referenced to the left earlobe. Horizontal and vertical EOG was measured with one electrode above and one on the outer canthus of the left eye. Scalp electrode impedances were kept below 5 kOhm and EOG electrodes were kept below 10 kOhm. EEG and EOG were amplified with a 10-s time constant and a 200 Hz low-pass filter, sampled at 1000 Hz, digitally low-pass filtered with a cut-off frequency of 30 Hz and online reduced to a sample frequency of 100 Hz.

Cardiac signal

Heart rate was measured from precordial leads. IBIs were determined by hardware R-peak triggering of the QRS-complex in the electrocardiogram. R-peak arrival times were measured by means of an event-recording interface with an accuracy of 1 ms.

Preprocessing of the signals

EEG

Since subjects had to respond only if a target letter appeared at the cued position, only RTs to relevant targets were available. Trials in which an incorrect response was given were excluded from further analysis as well as recordings with EEG or EOG deflections exceeding 70 μV. To prevent losing too many data because of eye movement artifacts, every trial was divided into two intervals for analysis (see Figure 1): *cue presentation* (0-800 ms) and *letter presentation* (800-1600 ms). After artifact detection the data appeared to be valid for further analysis of the letter-presentation interval, i.e. the part of actual interest for this study. Averages were calculated separately for each subject, electrode position and stimulus category. The averaged ERP amplitudes were aligned to a 100 ms pre-stimulus baseline.

Cardiac signal

Mean IBI times as well as spectral values of HRV were obtained by using the CARSPAN spectral analysis program (Mulder et al., 1995a). Spectral power indices of HRV are equivalent to the squared coefficients of variation in each of the corresponding frequency bands. The unit of these indices is called the *squared modulation index* (SMI, Mulder, 1992). Note that, in agreement with previous studies of our laboratories, we took the absolute power values for each of the frequency bands and did not relate them to total spectral energy. To approach normal distribution of the data for statistical analysis, all HRV spectral values were transformed into logarithmic values. We computed these indices for each of the three above-mentioned frequency bands (LF, MF and HF) and for the following eight periods: for the two rest periods of four minutes preceding and following task performance, respectively, as well as for six task periods, each containing 100 trials and also having a duration of four minutes. These periods were long enough for obtaining reliable spectral values in even the LF band, because the lowest frequency in this band (0.02 Hz) corresponds with a period duration considerably shorter than the rest and task periods at hand.

Data analysis

Performance measure

To investigate the differential influence of task Relevance on the children's perceptual sensitivity and decision bias, we computed d' and β for both the relevant and irrelevant condition. Computations were based on the conditional probabilities of, respectively, the correct detections and false alarms of the relevant condition, and the correct rejections of irrelevant targets and false alarms of both irrelevant targets and non-targets. For a detailed description of the computational steps we refer to Hochhaus (1972).

In both the relevant and irrelevant condition the signal to noise ratios were the same in terms of target vs. non-target occurrence. Yet the color cue told the children to neglect the signal in the irrelevant condition. This should result in more readily rejecting the signal in the irrelevant condition than confirming its presence in the relevant condition and, therefore, fewer false alarms to both irrelevant targets and non-targets. Hence, d' was expected to be increased in the irrelevant condition: the distance between the distributions of correct rejections and false alarms to irrelevant signals should be greater than the distance between the distributions of correct detections and false alarms in response to relevant trials. Likewise, we expected β to be decreased in the irrelevant condition since the bias for positively responding to irrelevant trials should be lower than the bias for positively responding to the relevant non-targets. Group differences were tested by a repeated measures design (GLM, SPSSPC, univariate F-statistics) with the within-subject variable Relevance consisting of two levels (relevant vs. irrelevant trials) and the between-subjects variable Group also consisting of two levels (intro- vs. extraverted). Separate runs were made for d' and β**.**

We further tested for group differences in the RT of the correct responses, which were available for relevant targets only. To this end we used a one-way ANOVA with the between-subjects variable Group.

If age was found to significantly correlate with any of the performance measures the group differences were adjusted for variations in age by including age as a covariate in the design.

ERPs

The N2b component, which is actually defined as the difference in amplitude from irrelevant and relevant signals, can be observed most reliably in nontarget ERPs because another long latency component, i.e. the P300, a prominent positivity occurring for targets only, is either absent in nontarget ERPs or too small to affect the N2b. For this reason MANOVAs were performed on the Relevance-dependent mean amplitude values of the ERPs elicited only by non-target stimuli. Since visual inspection showed that the N2b was strongest at Cz, analyses were confined to this electrode position. Mean amplitude values were computed for three successive intervals running from, respectively, 100-200 ms, 200-300 ms and 300 to 400 ms post stimulus (letter presentation).

The design we used was again a repeated measures design (GLM, SPSSPC, using univariate F-statistics), which now included two within-subject variables; i.e. the variable Interval, consisting of three levels, the variable Relevance, and the between-subjects variable Group. A selective attention effect was considered to be indicated by a main effect of Relevance. A main effect of Group would imply an overall difference in ERP amplitude between the two groups, which could not be attributed to differences in selective attention. A significant interaction between the variables Relevance and Group would be indicative of the two groups differing in their selectivity. A significant two-way interaction Interval × Relevance would be indicative of the Relevance effect differing for the three intervals, and a three-way interaction between Interval, Relevance and Group would indicate that the differential effect of Relevance holds for one or two specific intervals, in particular. Again, if age appeared to significantly affect the ERP amplitudes Group interactions were adjusted for age by including this variable as a covariate.

Cardiac measures

First of all we tested for group differences in *baseline* values. To this end we entered the rest values (averaged across both rest periods) obtained for the IBI times and the power of HRV in the different frequency bands (HF, MF, LF) in a multivariate design (GLM, SPSSPC) with the fixed factor Group (extraverted vs. introverted).

Group differences in cardiac *responsiveness* were tested by comparing the values obtained from the rest periods with those obtained from the task periods. Two types of RTD were analyzed by means of a repeated measures design (GLM, SPSSPC, univariate F-statistics) including the within-subject variable RTD with two levels (rest vs. task) and the between-subjects variable Group.

The first type of RTD referred to a comparison of the average across both rest values vs. the average across all task values. Group by RTD interactions should reflect group differences in general cardiac responsiveness to the task. To further test whether there are group differences in recovery from task performance, we applied another repeated measure design containing only the last rest and last task period as constituting the RTD factor.

Separate runs were made on the dependent variables: mean IBI time and HRV measured in, respectively, the HF, the MF and LF band. Again, in case RTDs in the measures could be shown to be affected by age, group effects were adjusted for the influence of age by including this variable as a covariate in the designs.

Results

Group differences

Performance measures

The two groups did not differ significantly from each other with respect to processing speed (RT; $F_{1,14}$ = .33; p=.55). They did, however, differ with respect to accuracy . Table 3a shows that the introverted children's perceptual sensitivity was slightly decreased in the irrelevant situation, while the extraverted children showed the expected increase. This is reflected by the interaction Relevance by Group (Table 3b), which, though not reaching statistical significance, has a large effect size and accords with the introverted children having made more false alarms to especially irrelevant targets than the extraverted children ($F_{1,14}$ = 2.03, p= .09; η^2=.14).

Table 3b also shows a significant main effect of Relevance on β reflecting the expected lower bias in the irrelevant condition. The significant Relevance by Group interaction reflects that this decrease is much greater for the extraverted children. This, however, is because these children were far less conservative in response to relevant trials (Table 3a), which agrees with the extraverted children having missed more relevant targets than the introverted children ($F_{1,14}$=2.42; p= .07; η^2= .16).

Table 3a. Group differences in performance measures. Means, standard deviations of d' and β in the relevant and irrelevant condition for introverted and extraverted children.

		Relevant		Irrelevant	
		M	*SD*	*M*	*SD*
d'	Intoverted (*n* = 8)	3.96	0.62	3.7	0.55
	Extraverted (*n* = 8)	3.7	0.68	4.1	0.52
Β	Introverted (*n* = 8)	1.24	1.1	0.94	0.11
	Extraverted (*n* = 8)	3.6	2.1	0.98	0.05

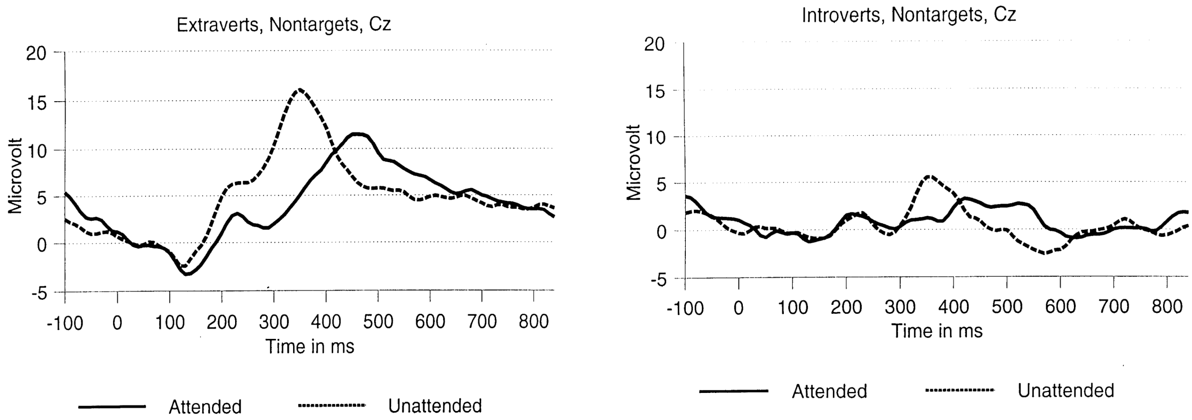
Table 3b. Group differences in performance measures. MANOVA results showing F-values, significance, effect sizes in terms of partial η^2 as well as the power observed (1-β).

	Group				Relevance				Relevance × Group			
	F(1,14)*	*p***	η^2	*1-β*	*F(1,14*)*	*p***	η^2	*1-β*	*F(1,14)*	*p***	η^2	*1-β*
d'		n.s.			3.3	.05	.20	.40	3.2	.06	.18	.38
Β	7.26	.01	.34	.71	11.26	.003	.45	.88	7.1	.01	.37	.70

** : Degrees of freedom for d' were 1 and 13 since it was adjusted for the effects of age that correlated significantly (r = .59; p = .01) with especially d' to relevant signals. ** : Tested one-sided. Note that effects with η^2 ≥ .14 are large effects, corresponding with Cohen's d ≥ 0.8.*

ERPs

Figures 2a and 2b show the ERPs in response to nontarget stimuli at the central Cz electrode position. The plots clearly suggest a larger N2b attention effect for extraverts (Figure 2a) than for introverts (Figure 2b).



a b

Figures 2a,b. ERPs in response to relevant (attended) and irrelevant (unattended) nontarget stimuli for extraverted and introverted children. The ERPs are aligned to a 100 ms pre-stimulus (letter presentation) baseline.

Our overall MANOVA revealed significant main effects of the factors Relevance ($F_{1,14}$ = 9.62; p= .008; η^2= .41; 1-β = .82) and Interval ($F_{1,14}$ = 9.82; p< .001; η^2 = .66; 1-β = .99) as well as, and this is more important, a significant interaction between Relevance and Interval ($F_{1,14}$ = 9.86; p= .007; η^2 = .41; 1-β = .83) indicating that the Relevance effect differs for the various intervals. Moreover, the 3-way interaction between Relevance, Interval and Group ($F_{1,14}$ = 2.1; p= .17; η^2 = .13; 1-β = .27), although not reaching statistical significance, had a moderate effect size suggesting that differential group effects of Relevance may occur for the three intervals. For these reasons separate MANOVAs were conducted for the three intervals and the results are summarized in Table 4, while Figure 3 presents the mean amplitude values for the groups and conditions analyzed.

Table 4 shows a main effect of Relevance in all three latency ranges, the effect being greatest in the 300-400 ms range. The analyses also confirmed the observed greater selective attention effect for extraverts (Figure 2a) as is indicated by the significant interaction effect Relevance x Group, which appeared to be greatest in the

200-300 ms latency range. Figure 3 illustrates that this effect is caused by no difference being found between irrelevant and relevant amplitude values being found for the introverted children, especially in the first two intervals (see also Figure 2b).

Tabel 4. (Differential) effects of Relevance on the Cz amplitude for non-target trials in three subsequent intervals following the letter presentation.

	Group				Relevance				Relevance x Group			
	F(1,14*)	*p***	η^2	1-β	*F*(1,14*)	*p***	η^2	1-β	*F*(1,14*)	*p***	η^2	1-β
100-200 ms		n.s.	.05		3.9	.04	.21	.45	3.14	.05	.18	.38
200-300 ms	3.3	.05	.19	.39	4.94	. 02	.26	.54	5.93	.02	.30	.62
300-400 ms	7.69	.01	.35	.73	10.49	.00	.43	.85	2.86	n.s.	.17	.35

** : The effects of age were not needed to be adjusted for since the regression of Relevance on age could be excluded to be significant. ** : Tested one-sided. Note that effects with η^2 ≥ .14 are large effects, corresponding with Cohen's d ≥ 0.8.*

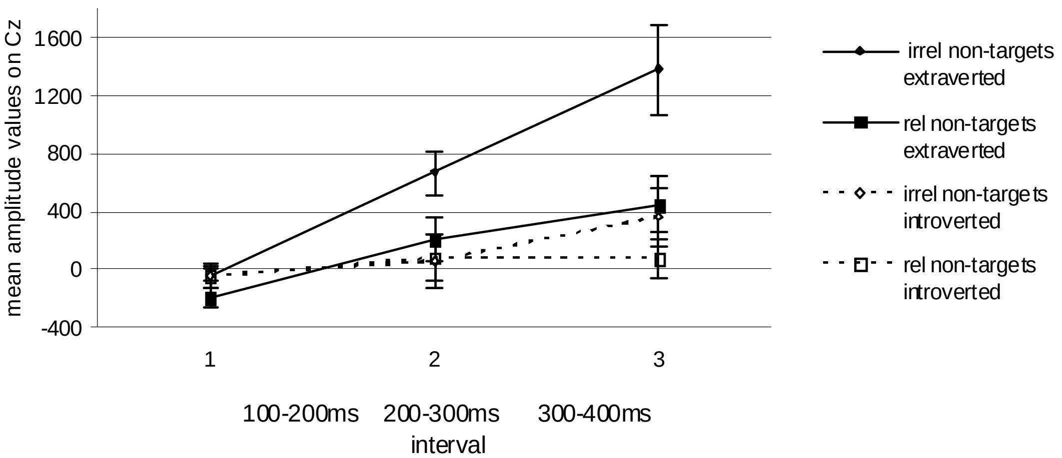
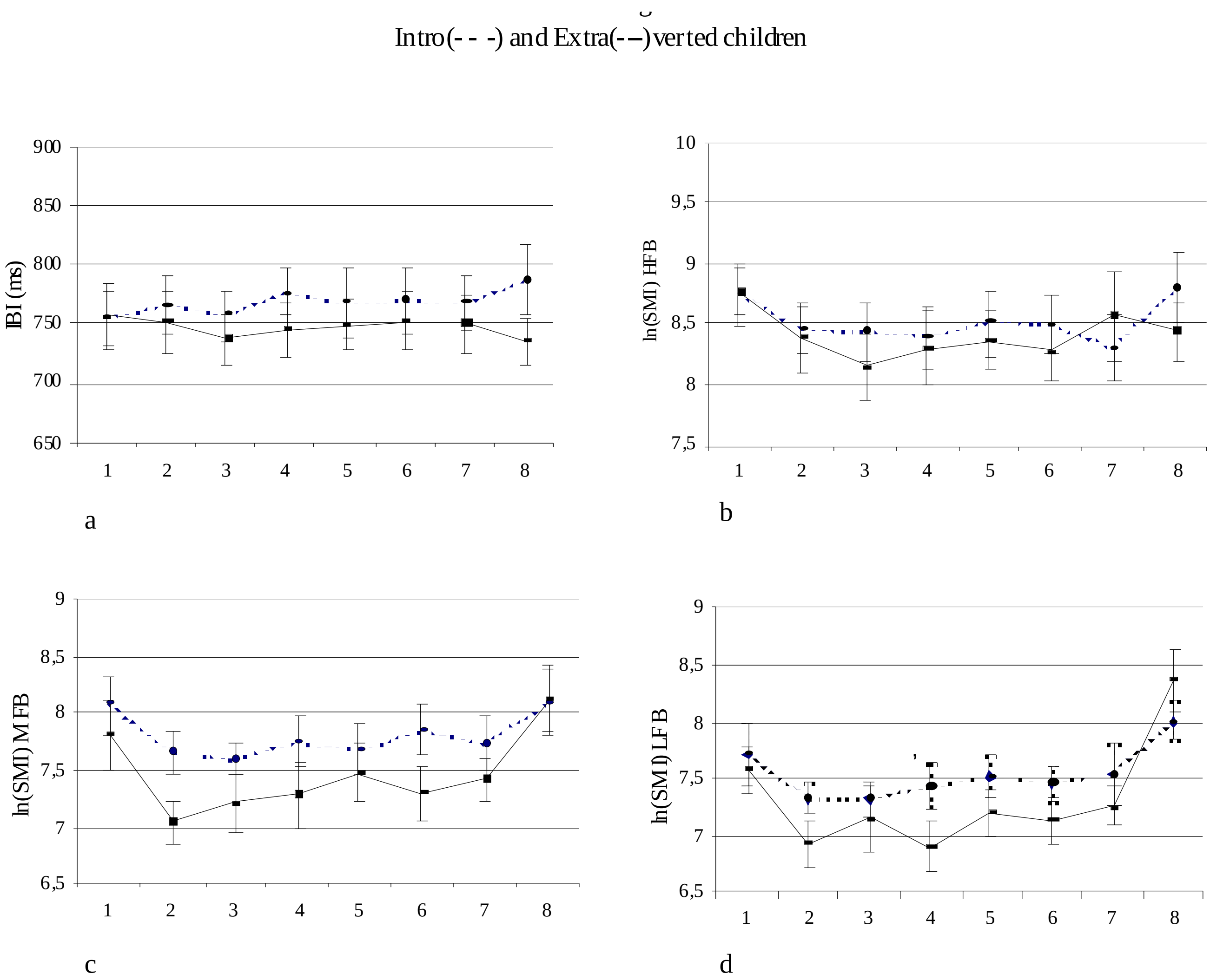


Figure 3. Mean values (and SEMs) for Cz-amplitudes of the ERPs in response to relevant and irrelevant nontargets.

Cardiac measures

First, the groups did not differ on any of our baseline measures, all effect sizes being very small: η^2 < .02. Significant cardiac responsiveness to the attention task as expressed in terms of overall RTDs was found for all HRV measures but not for the IBI times (see Table 5a and Figures 4a to 4d). The greatest RTDs were found for HRV measured in the LF band.



Figures 4a to 4d. Mean inter-beat interval times (a) and spectral power of HRV in HFB (b), MFB (c), and LFB (d) during two periods of rest (period 1 and 8) and six periods of task performance (periods 2 to 7). The solid lines refer to the extraverted children, the broken lines to the introverted children. Error bars present SEMs.

Moreover, the differences in HRV as measured in both, the LF and MF bands appeared to be more pronounced for the extraverted group than for the introverted group (Figure 4c and 4d). These differences turned out to be statistically significant as is indicated by the significant RTD x Group interactions, effect size and power being greatest for the LF band (Table 5a).

Table 5a. Cardiac responsiveness to task performance. RTD is defined as the average across both rest periods vs. the average across all task periods.

	RTD				RTD X Group			
	F(1,14*)	*p***	η^2	1-β	*F*(1,14*)	*p***	η^2	1-β
IBI			n.s.				n.s.	
HF	7.4	.01	.35	.72		n.s.	.01	
MF	43.1	.00	.76	1	3.88	.04	.22	.45
LF	74.6	.00	.84	1	8.87	.00	.48	.79

Tabel 5b. Recovery from task performance. RTD is defined as the last rest period vs. the last task period.

	RTD				RTD X Group			
	F(1,14*)	*p***	η^2	1-β	*F*(1,14*)	*p***	η^2	1-β
IBI			n.s.				n.s.	
HF			n.s.		1.8	.1	.11	.23
MF	21.5	.00	.61	.99	2.5	.07	.15	.31
LF	25.5	.00	.65	1	4.1	.03	.23	.47

*Abbreviations: IBI: Mean inter-beat interval times; HF, MF, LF: power of HRV in high- mid-, and low frequency band. *:The effects of age were not adjusted for since the regression of RTD on age could be excluded to be significant. ** : Tested one-sided*

With respect to recovery, large effects (with high power) were found for HRV in LF and MF bands. This effect was significantly greater for the extraverted children, in especially the LF band (Table 5b).

Summary and preliminary conclusion

Our data reveal that the extraverted children showed greater perceptual sensitivity to irrelevant trials than the introverted children. At the same time they showed a stronger selection-related evoked response in the EEG and greater cardiac responsiveness during task performance. Also, recovery from task performance appeared to be greater in the extraverted children.

Correlations among the measures

In order to get insight into how behavior, performance, the relevance-related ERP and the measured autonomic state changes are interrelated, we computed correlations among (1) the degree of extraversion operationalized as z(extraversion) - z(introversion), i.e. E-I in Table 1; (2) the difference between d' in the irrelevant and relevant condition (d'irrel-rel) as well as the difference between β in the relevant and irrelevant condition (βrel-irrel); (3) the magnitude of the N2b-complex; i.e. the differences in Cz-ERP amplitudes for irrelevant and relevant nontargets in the intervals of 100-200, 200-300, and 300-400 ms poststimulus (N2b100-200; N2b200-300; N2b300-400); and (4) the RTDs in HRV for the three frequency bands (RTD-HF; RTD-MF; RTD-LF) . Table 6 shows the correlations of the variables that correlated significantly with at least two of the other variables.

If we first take a look at the correlations of the degree of extraversion (E-I) with the performance measures, the magnitude of the N2b, and the RTDs in our HRV measures we see that it is significantly related with the difference in decision bias to relevant vs. irrelevant signals, the N2b-component in the first two intervals, and the RTDs in especially the LF HRV measure. These correlations imply that a higher extraversion score goes along with a greater discrepancy in decision bias to relevant and irrelevant signals, a greater *negativity* of the N2b (hence the negative sign) and a greater cardiac responsiveness in LF heart rate fluctuations.

The discrepancy in perceptual sensitivity (with d' being greater in response to irrelevant trials) appears to be highly correlated with both the N2b magnitude in the second interval and RTDs in low frequent HRV. The discrepancy in decision bias (with β being lower in response to irrelevant trials) is correlated with the magnitude of the N2b in the first two intervals and the rest-task changes in LF HRV.

Table 6. Correlations among the degree of extraversion, defined as $Z_{Extraversion}$-$Z_{Introversion}$ (E-I), performance measures, the N2b-complex and HRV in HF, MF and LF band.

	E-I	$d'_{irrel-rel}$	$\beta_{rel-irrel}$	$N2b_{100-200}$	$N2b_{200-300}$	RTD-LF	RTD-MF
E-I	-						
$d'_{irrel-rel}$	n.s.	-					
$\beta_{rel-irrel}$	.53; p=.02	.58; p=01	-				
$N2b_{100-200}$	-.63; p=.005	n.s.	-.58; p=.01	-			
$N2b_{200-300}$	-.69; p=.002	-.67; p=.004	-.45; p=.05	.57; p=.01	-		
RTD-LF	.62; p=.005	.63; p=.001	.61; p=.001	-.44 ; p=.03	-.65 ; p=.004	-	
RTD-MF	.47; p=.04	n.s.	n.s.	-.68; p=.002	n.s.	.53 ; p=.02	-

The N2b-component in especially the second interval is correlated with both the difference in perceptual sensitivity to irrelevant vs. relevant signals, the difference in decision bias as well as with the RTDs in low frequent heart rate fluctuations.

Directions completely agree with what may be expected from the former correlations: a greater N2b (negativity) is accompanied by a relatively greater perceptual sensitivity and relatively lower decision bias to irrelevant signals as well as by greater cardiac responsiveness. The magnitude of the N2b component in the 300 to 400 ms interval showed a correlation with only the RTDs in the MF band of HRV (r=-.52; p=.03).

With respect to the RTDs in HRV, changes in especially the LF band appeared to be correlated with both performance measures and with the N2b- negativity of the second interval. The correlations imply that greater cardiac responsiveness goes along with a relatively greater perceptual sensitivity and lower decision bias to irrelevant signals and a greater negativity of the N2b in the interval that showed the most effective discrimination between the extraverted and introverted children. HRV changes in the HF band correlated with only the discrepancy measure for perceptual sensitivity (r = -.56; p =.02). Note that this correlation, in contrast to the LF band, is negative, which implies that greater RTDs in HRV in the HF band go along with a smaller difference in d' for relevant and irrelevant trials.

Since we were not interested in testing that all null-hypotheses are true simultaneously but rather in tracing interrelations among the various variables in order to be able to interpret our findings on group differences we omitted statistical adjustment for multiple tests (see, Perneger, 1998).

Discussion

Our study revealed that the extraverted children turned out to be more selective, i.e. to show greater efficiency in ignoring irrelevant information, than the introverted children while exhibiting a significantly greater selection-related EEG-potential, and showing significantly greater autonomic responsiveness to the task. The first two findings confirm our hypotheses, while the significantly *smaller* autonomic responsiveness we found in the introverted children does not agree with what we expected based on literature.

Here we first of all would like to emphasize that the two groups did not differ in their baseline autonomic state. This means that, compared with each other, neither of the groups appeared to be generally hypo- or hyper-aroused, although the introverted children reported to have experienced a somewhat higher level of state anxiety than the extraverted children reported before starting the experiment. They did, however, differ in their arousability by task performance, this being greater in the extraverted children. Here it is remarkable that the most striking group differences were found for the RTDs in the LF band of HRV power, while no differences were found for task-related changes in mean IBI times and HRV power of the HF band. This suggests that the group differences in autonomic responsiveness to the task are less likely to reflect differences in parasympathetic (vagal) suppression but rather differences in sympathetic enhancement. Consequently, the extraverted children are likely to have shown a greater sympathetic response to task performance than the introverted children. This interpretation fits to the proposition of perceptual sensitivity being related to (changes in) the individual’s level of arousal, which is said to be predominantly noradrenergically controlled (Broadbent, 1971; Pribram and McGuinness, 1975; Sanders, 1983). The extraverted children showed the greater relevance-related discrepancy in perceptual sensitivity, which could be shown to highly correlate with both the RTDs in LF HRV power and the magnitude of the N2b-component in the second (and most effectively discriminating) interval. Changes in arousal, however, as mentioned in the introduction, have been related to the activity of the locus coeruleus, which has been found to affect the sympathetic part of the peripheral autonomic nervous system in particular.

This seems to contradict the suggestion by Van der Veen and colleagues (Van der Veen et al., 2000) that vagally controlled changes may be involved in selective attention. These authors found that transient cardiac slowing is elicited by inhibiting responses to irrelevant stimuli, and that this cardiac response is correlated with the magnitude of the N2b-component (Van der Veen et al., 2000). While, however, the Van der Veen group correlated phasic heart rate responses with performance and ERP-measures, we correlated the latter with tonic changes in autonomic state, because, as has been outlined in the introduction, we were interested in the relationships between the children’s temperament, their autonomic reactivity and their performance of a selective attention task. Investigations into the relationships between phasic cardiac responses and task-dependent autonomic state changes as measured by means of spectral analyses may provide some more insight into the dependency of trial-related cardiac responses on autonomic background activity. Returning to our own data, the *negative* correlation we found for the RTDs in HF band HRV and the discrepancy measure for d’ suggests that a greater vagal suppression might have gone along with less capacity for ignoring irrelevant targets due to attending to irrelevant trials too. Here is important to note that cardiac reactivity as measured in the HF HRV band did not discriminate between the groups.

Hence, it seems as if sympathetic enhancement facilitates a state of more efficiently ignoring irrelevant information, while vagal suppression goes along with active, attention-demanding processes. This could explain why vagal cardiac slowing is elicited by a process of active inhibition.

Regarding the children's decision bias, we found that its decrease from the relevant to the irrelevant condition discriminated between the two groups. It also correlated with LF HRV changes and, to a smaller degree, with the N2b-component in the second interval. Here we have to note, however, that the two groups of children did not differ from each other in their decision bias to irrelevant trials, which appeared to be decreased in both groups. Rather, the difference in their discrepancy scores was due to the extraverted children being less conservative in responding to just the relevant trials. Correctly responding to relevant targets, however, not only requires selectively attending to the validly cued position but also comparing the stimulus in mind with the actually presented stimulus. This process of evaluating the stimulus as a relevant target *follows* the selection process and is supposed to require comparisons to be carried out in working memory: the letter presented must be compared to a set of two alternatives. The number of serial comparisons to be carried out in working memory, i.e. the intensity of attention-demanding processing, has previously been shown to affect the degree of vagal suppression in healthy children (Althaus et al., 1999) and adults (Redondo and Valle-Inclan, 1992). Changes in low frequency power of HRV appeared to be unaffected by the *intensity* of processing (Althaus et al., 1998; Althaus et al., 1999).

The group differences found on the level of the children's decision bias may hence refer to another process than that of selection, i.e. a process that appears to be rather unaffected by the diminished changes in autonomic state that were found for the introverted children whose response bias to relevant signals was much more conservative. In this context another two correlations shall be mentioned that are not presented in Table 6. While the percentage of relevant targets missed turned out to be positively correlated with the RTDs in the LF band of HRV (r =.53; p =.02), there was a negative correlation with the RTDs in high frequent HR fluctuations (r=-.44; p=.05). This means that greater rest- task differences in HRV power of the HF band go along with a smaller percentage of misses, while the opposite holds for the RTDs in the LF band. This again, in our opinion, suggests a dissociation that can only be explained by the differential influences on changes in vagal and sympathetic activity exerted by the different types of cognitive processes that are activated during the performance of a task like the one administered in the present study.

In this context it is speculated that vagally modulated changes in heart rate may be associated with other, still later occurring ERP's derived from the relevant signals alone. These potentials are assumed to be closely related to the *intensity* of processing and include the P300, which is observed when the stimulus has been evaluated, as well as a serial search-related negativity involving the activation of working memory (Donchin et al., 1986; Kok, 2001; Okita et al., 1985; Polich and Kok, 1995).

Since the purpose of the present study, however, was to investigate only selective attention, we did not manipulate the number of serial comparisons to be carried out in working memory as well. Further studies with tasks in which both, selective attention and working memory capacity-related processes are manipulated should be able to test the hypothesis that the different processes differentially affect or are differentially affected by changes in, respectively, vagal and sympathetic activity and how these changes are related to processing-specific ERP components. For a more straightforward interpretation of the cardiac spectral measures in terms of sympathetically and parasympathetically controlled changes, however, still other measures of, in particular, sympathetic activity, such as derived from, for example, models describing the short term baroreflex control (Althaus et al., 1998; Van Roon et al., 2004) should be taken into account.

What may be the relevance of our findings to further (clinical) studies and what may be their contribution to theories of selective attention and its psychophysiological correlates?

We found that the two groups of children differed in their way of adjusting to the task demands. This, however, might have strictly been related to the task-inherent tempo of stimulus presentation (Stenberg et al., 1990; Van der Meere et al., 1995). Thinking in terms of continua ranging on the one hand from extravert behavior to externalizing disorders, and on the other hand from introvert behavior to internalizing disorders, we think that it is important to take into account (1) individual differences in temperament, (2) a multidimensional autonomic state concept, and (3) the specificity of the task paradigm, including event rate, when studying (selective) attention and its psychophysiological correlates in children with different types of internalizing and externalizing psychopathology.

With respect to the use of cardiac measures as autonomic state indices our study clearly proved the importance of (1) distinguishing baseline from reactivity measures, (2) not relying on mean heart rate alone, and (3) partitioning the spectrum of HRV into various frequency components. Here, we recommend, however, to use some additional measures, especially of sympathetic control, in order to better disentangle the different contributions of the two branches of the autonomic nervous system.

Finally, we realize that the number of subjects in our study was only small. High effect sizes and moderate to high correlations, however, suggest that replication of the experiment with a greater number of subjects would yield similar results.

Appendix

Items Extraversion:

1. Likes to talk about everything when family or friends come around.
2. Joins other children quickly and easily.
3. Is in a good mood.
4. Stands up for him/herself when other children threaten to take something away from him/her.
5. Expresses himself/herself easily, when there are difficulties at school, with friends, etc.
6. Quickly feels himself/herself at ease with unfamiliar persons.
7. Wakes up cheerfully every morning.
8. Defends himself/herself when he/she is treated unfairly.
9. Likes to talk about everything that he/she has experienced while playing.
10. Feels comfortable quickly in an unfamiliar environment.
11. Is exuberant while playing.
12. Sticks to his/her opinion when he/she thinks he/she is right.

Items Introversion:

1. Is withdrawn even when playing an enjoyable game.
2. Is obviously shy when a stranger asks something.
3. Dares to do less than peers when playing games.
4. Tends to be bullied by peers.
5. Smiles / laughs rarely.
6. Hesitates approaching people with whom he/she is unfamiliar.
7. Is afraid of thunderstorms and/or the dark.
8. Stands up too little for him/her herself with respect to other children.
9. Is more serious-minded than his/her peers.
10. Keeps in the background when unfamiliar people are visiting.
11. Is more afraid of playing in the playground (the jungle jim, for example) than his/her peers.
12. Play mates almost always get their way when playing with him/her.

All items were rated on a 4-points scale.