A psychophysiological approach to Sanders' and Mulder's cognitive-energetical information processing model: Contingent Negative Variation (CNV) in healthy 8-9-year-olds

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Tiivistelmä - Sandersin (1983) ja Mulderin (1986) kognitiivis-energeettistä tiedonkäsittelyn mallia lähestyttiin käyttämällä antisipaatioparadigmaa mukailevia, esitystahdiltaan hitaita, jatkuvaa tarkkaavaisuuden ylläpitoa vaativia tehtäviä (Continuous Performance Task, CPT). Tutkimuksessa keskityttiin CNV:hen (Contingent Negative Variation) terveiden 8-9-vuotiaiden lasten elektroenkefalogrammissa (EEG). Koeasetelmassa oli kaksi tehtävää: Tehtävä 1, jossa ei ollut motivaatioon vaikuttavia tekijöitä ja Tehtävä 2 jossa motivaatioon vaikuttavina tekijöinä oli kokeenjohtajan läsnäolo, palaute ja palkkio. Näiden tekijöiden vaikutuksia tutkittiin CNV:n amplitudin funktiona tehtäviä vertailtaessa. Tehtävässä 2 havaittiin kanavilla Fz, C3 ja Cz kasvanut korteksin negatiivinen potentiaali. Käyttämämme määritelmän mukainen CNV havaittiin ainoastaan kanavalla Fz. Lisäksi tutkittiin myös behavioraalisten mittojen (reaktioaika, virheiden määrä ja laatu) suhdetta CNV:n amplitudiin. Tehtävässä 2 negatiivisen potentiaalin amplitudilla oli positiivinen korrelaatio reaktionopeuden kanssa, kun taas virheiden määrällä ja korteksin negatiivisen potentiaalin amplitudilla ei ollut yhteyttä. Tulokset ovat samansuuntaisia aiempien tutkimusten kanssa, joissa on tutkittu motivaatioon vaikuttavien tekijöiden vaikutusta aikuisten CNV:hen. Sandersin ja Mulderin kognitiivis-energeettinen malli pystyy selittämään saadut psykofysiologiset tulokset, mikä puoltaa mallin soveltamista terveiden 8-9-vuotiaiden lasten tiedonkäsittelyä tarkasteltaessa.

Avainsanat: CNV; CPT; kehitys; lapset; motivaatioon vaikuttavat tekijät

A psychophysiological approach to Sanders' and Mulder's cognitive-energetical information processing model: Contingent Negative Variation (CNV) in healthy 8-9-year-olds

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Abstract - Sanders' (1983) and Mulder's (1986) cognitive-energetical information processing model was approached by utilizing slow event-rate Continuous Performance Tasks (CPT's) with focus on Contingent Negative Variation (CNV) in the electroencephalographs (EEG) of healthy 8-9-year-old children. The CPT-design consisted of two task conditions: Task 1 without and Task 2 with motivational factors experimenter presence, feedback and pay-off. The overall effects of these were investigated as a function of CNV amplitude in the task comparisons. In Task 2, increased negative cortical potential was found in channels Fz, C3 and Cz. The CNV proper was observed only in channel Fz. The relation between behavioral measures (reaction times, amount and type of errors) and CNV amplitude was also examined. In Task 2, negative potential had a positive correlation with fast reaction times (RT's), whereas no correlation was observed in relation to negative potential and the amount of errors. The results are in line with previous adult studies of effects of motivational factors on CNV. The cognitive-energetical information processing model is capable of explaining the results which supports use of the model in consideration of healthy 8-9-year-olds.

Key words: Contingent negative variation; Continuous Performance Task; Development; Children; Motivational factors

The present paper is the first part of a series of experiments which aim to investigate underlying psychophysiological mechanisms of information processing in attention deficit hyperactivity disorder (ADHD) and conduct disorder (CD) with/without ADHD. In addition, forthcoming series of experiments will also focus on dyslexia which is common to both ADHD and CD. The information processing is conceptualized by using Sanders' (1983) and Mulder's (1986) model as a theoretical basis and approached utilizing a slow event-rate Continuous Performance Task (CPT) assumed to entangle the core problems of ADHD (van der Meere, Stemerdink & Gunning, 1995a; van der Meere, Hughes, Börger & Sallee, 1995b; van der Meere, Shalev, Börger & Gross-Tsur, 1995c). The present paper will focus on the effects of motivational factors on event related potential (ERP) of the brain in the electroencephalographs (EEG) of healthy 8-9-year-olds. Special emphasis is attached to ERP-component contingent negative variation (CNV). Behavioral measures and their relations to the CNV are further considered.

The so-called structural approach is the traditional way of sketching information processing. Within this paradigm, research methodology is based on reaction time designs. The Additive Factor Method (Sternberg, 1969) is widely utilized in reaction time (RT) analysis. Processing of the task is assumed to comprise of a sequence of independent processing stages, each stage receiving information from the preceding stage and transmitting the processed information to the successive stage. Existence of the processing stages can be inferred by observing effects of the experimental factors on total processing time. If two experimental factors have additive (independent) effects on reaction time, then they are assumed to affect two separate stages. On the other hand, if two factors affect a common stage, the effect on the reaction time is interactive. Following this approach, Sternberg (1969) established four stages of information processing: 'encoding', 'memory search', 'decision' and 'motor organization'.

Sanders' (1983) cognitive-energetical model is based on Sternberg's information processing theory, but makes an expansion towards a more psychophysiologically oriented functional approach (for review, see e.g. van der Molen, Bashore, Halliday & Callaway, 1991). The model assumes that the information processing system contains cognitive-energetical resources which are used to modify the processing of information towards optimal performance (Mulder, 1986).

The four stages of information processing in Sanders' model include 'stimulus preprocessing', 'feature extraction', 'response choice' and 'motor adjustment'. The second level of the model, connected to the processing stages, includes three distinct inter-connected energetical mechanisms containing the pools of processing resources: arousal, activation and effort. The pools of arousal and activation allocate energetical resources to the processing stages 'feature extraction' and 'motor adjustment' respectively. The main function of the effort pool is to control arousal and activation. The energetical mechanisms and the processing stages are connected to the evaluation mechanism, which monitors and controls these via two types of feedback: one reflecting physiological state of the system and the other

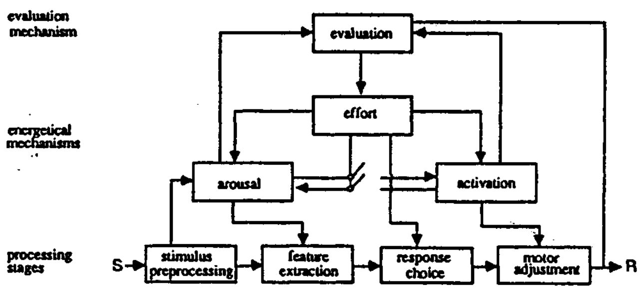

Figure 1. Simplified illustration of the cognitive-energetical model of human information processing (Sanders, 1983).

performance adequacy. The effort pool uses this feedback to modify performance indirectly via the pools of activation and arousal and also directly via the processing stage 'response choice' (Sanders, 1983). Figure 1. represents a simplified illustration of the cognitive-energetical information processing model.

The focus of this paper will be on the effort pool necessitating further consideration of its role. Effort has two aspects in the model: one related to control of state and the other to evaluation mechanisms conscious processing, decision making and reasoning. The control of state refers to effort's ability to compensatory control of sub- optimal (either too high or low) arousal and activation functioning. Effectiveness of effort and the performance as a whole are dependent on variables such as time-on-task, task monotony (boredom) and motivational factors, such as experimenter absence/presence, knowledge of results (feedback) and pay-off (Sanders, 1983; Mulder; 1986, van der Meere, 1996). For example, a monotonous CPT with low stimulus density (slow event-rate) produces a sub-optimal state of under-activation, which must be compensated by effort pool in order to maintain an acceptable level of performance. Inability of the effort pool to exert resources to maintain an optimal state results in slow, inaccurate responding. On the other hand, over-activation induced by fast presentation rate must also be compensated by the effort pool. This sub-optimal state results in fast inaccurate responses (Sanders, 1983).

According to Mulder (1986), the psychophysiological basis of the cognitive-energetical model has been derived mainly from studies of heart rate dynamics. In the same paper, he suggested that Heart Rate Variability (HRV) reflects only the mobilization of resources during information processing, whereas more central measures, such as measurements of ERP's of the brain, are more specific in revealing the nature of the resources. He further argued that mechanisms of effort, arousal and activation are reflected in amplitude variations in the ERP components. Arousal is reflected in the early components, while the late movement related components represent the activation pool. The effort pool is manifested in P3 and Slow Wave (SW) components such as the CNV.

The CNV was initially reported by Walter, Cooper, Aldrigde, McCallum and Winter (1964). It develops during a warned fore-period prior to an event, reflecting processes of expectancy and preparation (reviewed by e.g. Rockstroh, Elbert, Birbaumer & Lutzenberger, 1982). Largest amplitudes are obtained from the central (vertex) and frontal areas (Coles, Gratton & Fabiani, 1990). Commonly, two distinct phases are distinguished: the early CNV or orienting-wave (O-wave) and the terminal CNV or expectancy-wave (E-wave) (Rohrbaugh & Gaillard, 1983). The O-wave is commonly associated with an orienting response, while the role of the E-wave is not so certain (e.g. McCallum, 1988). According to Rohrbaugh and Gaillard (1983), it is closely related to the motor readiness potential (RP), while Simons (1988) linked it to non-motor, particularly affective processes.

Rockstroh and her co-workers (1982; Rockstroh, Elbert, Canavan, Lutzenberger & Birbaumer, 1989) suggested that CNV reflects enhanced cortical excitability enabling a preparatory state or potentiality for cerebral processing in the underlying networks. In contrast, heightened positivity may result from a lowered excitability in cortical neuronal networks. This 'preparatory state' or 'potentiality' should be reflected at least as a positive correlation between negative cortical potentials and fast responses (Rockstroh, Müller, Wagner, Cohen & Elbert, 1993). This positive correlation is frequently observed, although modest at best. McCallum (1988) shared a similar view, he suggested that the observed positive correlation between the CNV and fast responses reflect separate underlying processes of anticipation rather than a single process of preparation.

According to Walter's (1971) developmental studies, CNV is absent before age 4 and systematically present after age 11. Cohen's (1973, 1976) studies were congruent with Walter's. Cohen found a linear increase in CNV amplitudes throughout ages 6 – 18. CNV amplitude levels equal to adults' were reached at age 15. Results of CNV studies in children seem to be dependent on the motivational value of the stimuli. Low and Stoilen (1973) were unable to evoke a CNV with non-motivating stimuli until after age 9 or 10, whereas using interesting kaleidoscopic stimuli, Gullickson (1973) evoked CNV's in 2- and 3- year- olds.

In the present paper we focus on the CNV in the EEG of healthy 8-9-year-olds using CPT's with and without motivational factors (experimenter absence/presence, feedback, pay-off). Based on Walter's (1971) and Cohen's (1973, 1976) developmental findings, we assume that CNV is present in healthy 8-9-year olds. According to van der Meere (1996), the motivational factors are capable of affecting resources of the effort pool. Manipulation of effort's resources is further reflected in the respective psychophysiological correlate CNV (Mulder, 1986). Thus, motivational factors in the present study are assumed to produce a significant increment in the CNV amplitudes. The manipulations on effort pool are expected to be reflected in the behavioral measures, that is, less errors, faster and less variable responses should occur as a result of augmented cortical negativity.

Method

Subjects

An original sample of 27 rewarded pupil volunteers from a local primary school participated in the study. In order to ensure the absence of attentional, conduct and emotional problems, a Finnish translation of the Conners' scales (Goyette, Conners & Ulrich, 1978) for parents and teachers was administered. All subjects were further tested for word recognition and comprehension of sentences (Lindeman, 1998) as well as spelling (Häyrinen, Serenius-Sirve & Korkman, 1999) to confirm normal reading abilities. On the basis of these tests, 3 subjects were excluded. In addition, data from 6 subjects were excluded due to poor data quality. As a consequence, the final sample included 18 subjects (11 males and 7 females). The mean age was 8 years and 9 months (SD= 3.3 months and age range from 8 years and 2 months to 9 years and 4 months). Subjects' handedness was confirmed with a test of motor skills (Henderson & Sudgen, 1992). Only one of the eighteen subjects was left-handed.

Design and Procedure

The subjects performed the tasks in a sound attenuated, dimly lit and electrically shielded room. Subjects were seated in front of a table 130 cm from the display. The table containing the response button was adjustable to allow a comfortable position.

The experimental room was connected to the adjoining room with a bi-directional communication system.

A 5 minute period for heart rate (HR) baseline measurement and an 11 minute auditory ERP session utilizing a new method for studying mismatch negativity (MMN) (Pihko, Leppäsaari & Lyytinen, 1995) preceded the two continuous performance tasks. After these the HR- baseline was measured again. Results of the HR and auditory ERP measurements will be considered elsewhere.

The two CPT's were based on the traditional two-stimulus anticipation paradigm (S1-S2 paradigm). Contrary to the traditional anticipation paradigms, the trial length was varied. The S1, which was displayed immediately after offset of preceeding S2, was of either fixed duration (6500 msec in every second trial) or of variable duration (5500, 6500, 7500 or 8500 msec (mean 6500 msec)) in a pseudo-randomized order. This design was necessary to allow proper ERP measurements in which the fixed trial length is needed, while permitting the required variation in the stimulus presenting sequence required in proper RT measurements. Furthermore, a sufficient amount of ERP trials for averaging was obtained without unnecessarily prolonging the task. Unlike the S1, the duration of S2 was always constant 500 msec. The S1-S2-sequence was kept the same in both tasks including a total of 240 trials in 29 minute task conditions. The fixed 6500 msec trials are referred to as ERP-trials.

Both task conditions (Task 1 and Task 2) were similar to each other, with the exception of the motivationals factors which were introduced in Task 2. The tasks were preceded by an instruction, which emphasized speed and accuracy and informed the subjects to adopt a relaxed position and to avoid unnecessary body movements. In these tasks, the subjects were to focus on a "plus" symbol (the S1) in the center of the display and to make a choice reaction depending on the type of following S2 stimuli. The S2 was either an asterisk (p= .75) which demanded a fast button press or alternatively a circle (p= .25) which required no response. The color of stimuli was white (sized 1.5 x 1.5 cm) and they were presented on blue background. Subjects were instructed to press the response button relative to an asterisk with the index finger of the dominant hand and to inhibit the response in the case of a circle. Full comprehension of the rules was confirmed during a 5 minute training session under experimenter supervision before both tasks.

The subjects always performed Task 1 before Task 2 in which the motivational factors were introduced. That is, the experimenter was present, subjects had a reward of 48 FIM at the task onset and feedback of performance was provided. The experimenter subtracted 2 FIM per error during the presentation of the feedback bar (vertical bar indicating remaining money). The feedback was provided on the display 500 msec after every S1-S2-pair with fixed duration, that is, after every two trials. There were two major error types in both tasks: omissions (misses) and commissions (false alarms). Also, responses faster than 200 msec or slower than 2000 msec were considered as errors. The presentation sequence of fixed and variable length trials and feedback are illustrated in Figure 2.

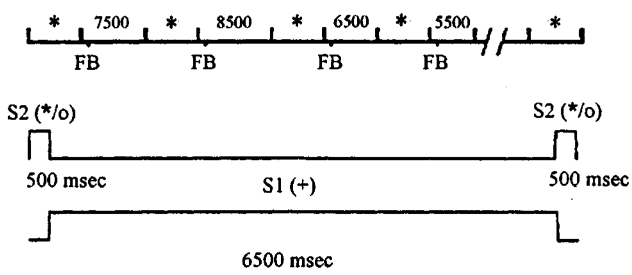

Figure 2. On the above, a schematic presentation of the trial sequence where * represents the ERP-trials. The FB illustrates presentation of feedback in Task 2 after trial with fixed length. The figures represent trials with variable length (5500, 6500, 7500 or 8500 msec). On the bottom, a presentation of a single ERP-trial (S1-S2-pair with S1 duration of 6500 msec). The square waves represent the presentation of S1 and S2 and the symbols in parentheses the S1 and the S2 types.

Electrophysiological recordings

An Amiga 2000 computer was used for the control of experiments, presenting and timing of stimuli and storage of the behavioral responses. The EEG-recording system was based on the Bio-logic Brain Atlas-system. Data acquisition of electrophysiological responses was conducted with Tecmar's Labmaster 12-bit, 16-channel AD-converter and DSAMP software run on a 233 MHz Pentium PC.

The EEG was recorded according to the international 10 – 20 system (Jasper, 1958) mid-sagittally at frontal (Fz), central (Cz) and parietal (Pz) electrodes. The lateral electrode placements were at C3 and C4. The electrooculograph (EOG) was obtained with electrodes positioned below the canthus of the right eye and above the canthus of the left eye approximately 2.0 cm from the pupil. Linked mastoids were used as a reference for both EEG and EOG recordings. The epidermis underneath the EOG and mastoid electrodes was prepared by cleansing with Neo-Amisept isopropyl alcohol and removing the outer layers of the epidermis by rubbing with abrasive Omni Prep paste. Neuroline (Type 725-01-K) disposable silver-silver chloride electrodes were used. The EEG was recorded by using an EEG-cap (ECI). In all electrodes, ECI Electro-gel served as the conducting agent. The impedance level was always below 10 kΩ and mostly within 1-2 kΩ. Bandpass of DC (0.0 Hz) – 70.0 Hz and sampling rate of 200 Hz were used in the recording. The EEG sampling was begun 2500 msec before the S1 and ended 3000 msec after the S2 onset in ERP-trials, resulting in a total trial length of 12000 msec.

Data Reduction and Analysis

The raw-EEG of each subject was inspected visually trial by trial in order to determine an appropriate exclusion criteria for EOG- and movement related artifact. Consequently, trials contaminated by EOG shifts or movement artifacts in the EEG which exceeded ± 70 μV and occurred between the onset of preceding S2 and offset of succeeding S2 were excluded from further analysis by using the DSAMP-program. Data of 6 subjects were excluded from the analysis due to technical flaws or insufficient number of uncontaminated trials (less than 50% of trials). From 240 trials per task, only 120 trials containing fixed duration S1-S2-pairs were averaged, since averaging the remaining trials of variable duration would have produced results with nonsense content. Both task conditions were split in two 60 trial blocks in order to analyze time-on-task effects. The mean number of trials after exclusion of EOG- and movement related artifact was 85.8 in Task 1 (45.9 in block 1 and 39.9 in block 2) and 102.1 in Task 2 (50.6 in block 1 and 51.5 in block 2).

Averaged ERP's were used in statistical analyses of electrocortical responses. The convention of setting the ERP-baseline to the onset of S1 was not suitable due to trial sequence; the ERP components evoked by the preceeding S2 are riding on the top of the responses evoked by the S1. In the present study, this way of setting the baseline would have resulted in an inappropriate baseline. As evident in Figure 3. (see Results section), the baseline would have been at the peak of the P3- like positive wave. In order to exclude this effect on the analyses, the baseline was set to the onset of S2 of the preceding trial. The CNV was defined as statistically significant mean negative shifts during the intervals 1500-2000 msec, 3750-4250 msec and 6000-6500 msec (Interval 1, Interval 2 and Interval 3, respectively) following the S1 onset.

The statistical analyses were performed using SPSS 8.0 for Windows software. A MANOVA design for repeated measures was conducted with task (two levels: Task 1 and Task 2), block (two levels) and Interval (three levels) as the within subject factors. In order to investigate more specifically the potential differences between the tasks, a t-test for paired samples was used to compare the respective intervals in all EEG-channels during Task 1 and Task 2. The Pearson correlation was calculated between the CNV-amplitude (the potential difference between Interval 1 and Interval 3) and behavioral measures (mean RT's, variance of RT's, number and type of errors) in Task 1 and Task 2. The behavioral measures were calculated from the 120 fixed duration S1-S2-pairs. A t-test for paired samples was used in task and block comparisons.

Results

Figure 3. illustrates across subject averages of cortical potentials during the 6500 msec inter-stimulus-interval in both task conditions. The square pulses on channel 'Mark' represent the consecutive S2's. The S1 was visible during the time interval in between two S2's. In the Task 2 the early ERP components evoked by the preceding S2 are followed by a steady increase of negativity until the onset of the succeeding S2. This increment of negative cortical potential is not seen during Task 1.

Statistically significant CNV was reached only in Fz ($F(2, 16)=9.16$, $p< .01$) in Task 2. A significant main effect of Task was found in channels C3 ($F(1, 17)=5.34$, $p< .05$) and Cz ($F(1, 17)=5.61$, $p< .05$), whereas it was not observed in channels C4 and Pz. Also, Task and Interval interacted ($F(2, 16)=6.64$, $p< .01$) significantly in channel Fz. A t-test for paired samples indicated significant potential level differences between the tasks in the Intervals 2 and 3 in channels Fz, C3 and Cz cortical potentials being more negative in Task 2. The comparisons of electrocortical responses are summarized in Table 1. Again, the channels C4 and Pz showed no significant difference between the tasks. In considering Interval 1, the tasks did not differ in any channel. The block averages of electrocortical responses did not differ significantly from each other in any channel in either of the tasks.

Considerable inter-individual variance in electrocortical slow wave patterns was observed. For example, one subject presented an atypical slow wave pattern in both task conditions: a strong negative shift followed the S1 onset peaking at approximately 2000-3000 msec but it returned towards the baseline before the S2. This phenomenon was especially salient during Task 1 (Figure 4.). In addition to atypical slow wave pattern, the subject had extremely slow RT's compared to other subjects in Task 2 (mean RT's 818,0 msec; Z-value above 1.96).

There was an association between fast RT's and augmented negative cortical potentials in Task 2. A significant positive correlation was found between fast RT and amplitude of negative shift in channels Fz, C3 and Cz ($r= .56$; $r= .49$; $r= .51$, $p< .05$ for each, respectively). The association between amplitude of negative shift and number of errors was generally insignificant.

The behavioral results are illustrated in Table 2. The responses in Task 2 were significantly more accurate than in Task 1 ($t(17)= 3.51$, $p< .01$). The tasks differed in response speed (RT in Task 1 545.6 msec and 572.9 msec in Task 2), but the difference did not reach statistical significance. The same applies for blockwise comparisons of RT's. Also, the standard deviations (SD's) did not differ significantly between the tasks or blocks.

Table 1. Differences in cortical potentials and statistically significant t-values of paired samples t-test between Task 1 and Task 2 in Intervals 1, 2 and 3.

Int.		Fz	C3	Cz	C4	Pz
1	diff.	1.63	2.00	1.44	2.22	1.59
	t-value	n.s.	n.s.	n.s.	n.s.	n.s.
2	diff.	6.84	3.41	4.54	2.21	0.74
	t-value	2.92**	2.17*	2.49*	n.s.	n.s.
3	diff.	10.83	4.95	6.45	2.29	0.54
	t-value	4.33***	2.41*	2.50*	n.s.	n.s.

Note: Diff. represents the difference in cortical potentials between the tasks in μV. Int. represents Intervals 1, 2 and 3.
* $p < .05$. ** $p < .01$. *** $p < .001$. n.s $p > .05$.

Table 2. Mean reaction times (RT), standard deviations (SD) of RT's and the amount of wrong responses (WR) to Task 1 and Task 2 separately for the two blocks.

	RT	SD	WR
Task 1	545.6	147.1	25.3
Block 1	541.0	137.2	11.7
Block 2	550.5	151.3	13.6
Task 2	572.9	145.6	15.1
Block 1	562.1	143.8	8.4
Block 2	583.2	139.6	6.7

Note: RT and SD in msec.

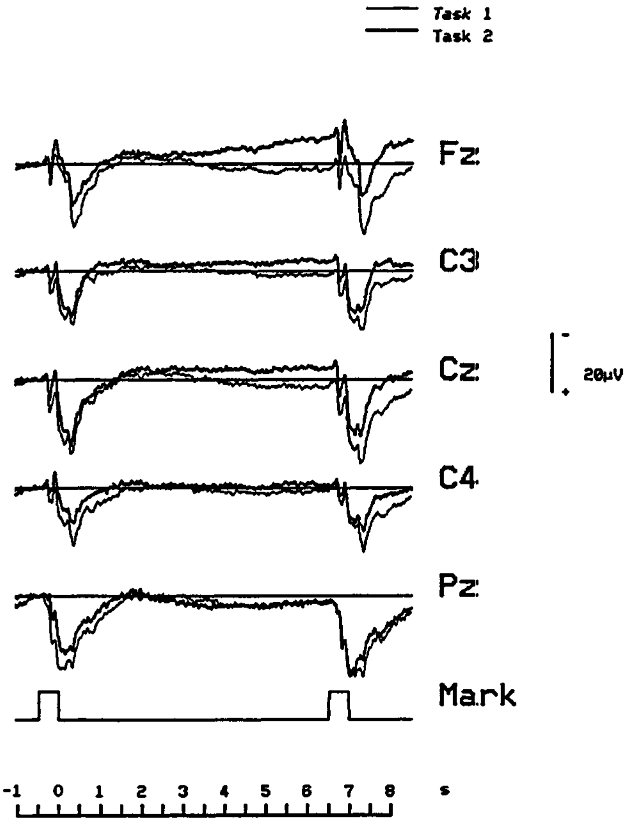

Figure 3. Across subjects average of slow wave responses during Task 1 and Task 2.

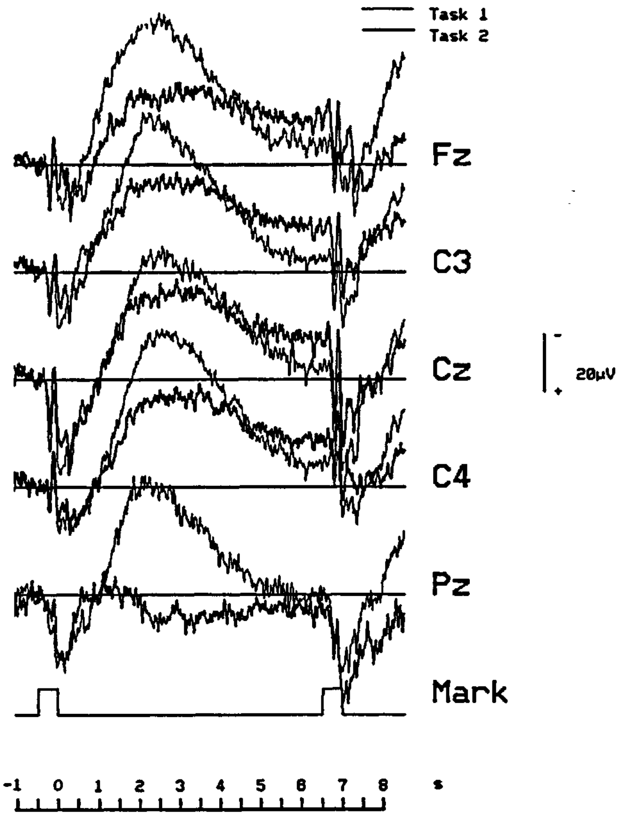

Figure 4. Single subject average of atypical slow wave responses during Task 1 and Task 2.

Discussion

Based on previous studies (Sanders, 1983; Mulder, 1986; van der Meere, 1996), the monotony in Task 1 was supposed to require an excessive investment of resources of the effort pool in order to maintain an optimal level of performance. In other words, stable performance level in the task is due to optimal compensatory effort, whereas a labile level of performance indicates insufficient compensation. An enhanced level of performance was expected in Task 2, since motivational factors provided effort pool with additional resources. Adopting Mulder's (1986) view, the compensatory functioning of the effort mechanism was supposed to be reflected multi-dimensionally. In the physiological dimension, increased investment of effort mechanism's resources were expected to result in augmented CNV-amplitudes, whereas in the behavioral dimension the increase in effort was assumed to result in enhanced accuracy and accelerated speed of the responses.

Task 1 was unable to induce the CNV: after the P3 component, the slow wave potentials returned to baseline. Mulder (1986) suggested that CNV amplitudes are lower in conditions where resources of effort are vastly required (e.g. in a prolonged, monotonous task without pay-off and knowledge of results when experimenter is absent). This argument, in addition to developmental findings (Cohen, 1973; Gullickson, 1973; Low & Stoilen, 1973), suggested the presence of a low-amplitude CNV. However, total absence of CNV proper was not expected. Subjects' accuracy in Task 1 was significantly worse than in Task 2, while response speed remained at the same level. Poor accuracy in the Task 1 is in line with the hypothesis, while response speed differed insignificantly between the tasks, the RT's in Task 1 being faster than in Task 2. This difference in RT's was in opposition to the hypothesis, since previous studies (van der Meere, 1996) suggested accelerated response speed when motivational factors are introduced.

In consideration of the cognitive-energetical model, the results of ERP analyses (Table 1.) are parallel with observed behavioral results (Table 2.). They might be best explained in terms of effort's compensatory functioning, to be more precise, the results may be due to an inability to allocate the effort pool's resources properly or its insufficient resources. Task 1 provided no factors intended to facilitate the effort pools' functioning whereas the motivational factors introduced in Task 2 had an expected effect on compensatory functioning implying that the effort pool's resources were significantly increased. The effect of motivational factors during Task 2 was indicated as the CNV frontally and increased negative cortical potentials centrally and also as substantially enhanced accuracy in the task. These findings suggest that the effort pool's resources were insufficient or improperly allocated during Task 1. On the other hand, it may be argued that absence of CNV and poor accuracy in Task 1 reflect only lack of motivation and therefore resources of the effort pool are not invested.

Previous research suggests that the effect of motivational factors on behavioral measures is reflected in response speed, its variation, or accuracy of responses (Sanders, 1983; Mulder, 1986; van der Meere, 1996). In addition, changes in these measures might be thought to be due to the instruction given, that is, if speed is emphasized, the effect of effort is visible in faster responses. The same logic also applies to accuracy. In the present study, the instructions placed equal emphasis on speed and accuracy. An optimal balance between speed and accuracy was reached during the training sessions. Although the instructions emphasized both of these, only accurate responding was rewarded in the Task 2, since the time given to respond (2000 msec) might have been too long to drive subjects towards fast responding. Consequently, it is possible that subjects adopted an accurate and therefore beneficial response strategy in Task 2 in order to maximize the reward. Maximization of accuracy seems improbable to happen in parallel with the production of faster responses. It is equally possible that the response speed was already maximal in Task 1, leaving little room for faster reactions.

The idea of response strategy comes close to the conscious processing, reasoning and decision-making aspect of the effort pool in the Sanders' cognitive-energetical model. This aspect stresses the cognitive perspective in compensatory processes. The response strategy adopted might affect the balance between direct and indirect connections used in the allocation of processing resources. The direct connection refers to the link between effort pool and 'response choice', whereas the indirect connection refers to the resource allocation via the pools of arousal and activation to the processing stages. Based on studies focusing on ADHD, Van der Meere (1996) argues that a deficit of effort/activation forms the core problem in hyperactivity, resulting in slow and inaccurate responding. This view is supported by Frowein (1981), who claims that the activation pool is closely related to response speed and it may be enhanced with amphetamines. Indirect allocation of resources is linked to processes performed by the stage of 'motor adjustment' which efficiency is reflected in the response speed. Therefore, one might suggest that resources of the effort pool invested in this way might be reflected in faster responses. On the other hand, a strategy emphasizing accuracy might change the balance towards the direct connection between the effort pool and the 'response choice' stage. This should result in enhanced accuracy, while the speed remains the same. The fact that the response speed in the tasks did not differ significantly while accuracy was improved, due to increased resources of compensatory effort in Task 2, supports such an assumption.

A consistent finding in CPT's is the time-on-task effect, which refers to performance deterioration as a function of time. This phenomenon is commonly probed by dividing the tasks into, for instance, three blocks and comparing the performance between them. According to the cognitive-energetical model (Sanders, 1983), this phenomenon is related to exhaustion of the effort pool's resources and should be reflected as an attenuation of the CNV (Mulder, 1986). However, the block-wise comparisons, using the first and the second half of the task as blocks, revealed no differences in slow wave responses in either of the tasks. In addition, the analysis of behavioral data resulted in a similar finding: no statistically significant differences in response speed, its variance or accuracy between blocks within either of the tasks were observed. This might suggest that the level of performance did not change significantly within the tasks as a function of time. This is not in line with previous studies (e.g. van der Meere et al. 1995a; 1995b; 1995c), where the time-on-task effect is commonly observed as slower and more variable response speed and less accurate responses. However, this discordance between the present and previous studies might be due to the experimental design, which is not optimal for this type of consideration since the amount of trials needed for averaging of the ERP-responses determined the minimum block length. The insufficient number of blocks may have confounded the time-on-task effect and therefore these analyses should be considered with caution. It is plausible to assume that a design with fixed trial length, and therefore greater number of trials for averaging, could have revealed the absent time-on-task effect in ERP-responses.

Rockstroh et al. (1993) proposed that CNV might reflect a general preparatory state or potentiality. They further suggested that this potentiality, or enhanced cortical excitability, is reflected at least in fast motor responses. In contrast, slow positive shifts, 'disfacilitation', may result in lowered performance levels. Furthermore, in the present study, a significant positive correlation between fast RT's and increased negative cortical potentials was found in channels Fz, C3 and Cz during Task 2. However, Rockstroh et als'. argument is not supported by the electrocortical- and behavioral data. The tasks did not differ in RT's in spite of the difference in negative cortical potentials whereas the subject's accuracy was better in Task 2 where negativity of electrocortical responses was also increased. Although no significant correlation between the amount of errors and negative cortical potentials was found, the absence of correlation could be due to the small number of wrong responses. Low variance in the number of wrong responses might in turn, result in a weak association with the amplitude of negative cortical potentials. However, the insignificant correlation does not exclude the possibility of such a relationship. One could wonder whether the possible association is confounded by the statistical obstacles.

The electrocortical results are concordant with the literature considering the topography of CNV (e.g. Coles et.al., 1990): the negative shift was most pronounced frontally and centrally. In Task 2, negativity was increased in location C3, while the contra-lateral location C4 was insensitive to manipulations. Most of the subjects (17) were right-handed and therefore the asymmetry might be related to processes associated with preparation of motor response as supposed by Rohrbaugh & Gaillard (1983). Although this assumption of pure motor preparation had no direct evidence, the link between CNV and response speed gives it some support. This assumption is complicated by the fact that the CNV was most pronounced frontally, since this topography might be related to more general processes beyond pure motor preparation. It is also possible that slow wave shifts recorded from various locations on the scalp might reflect different preparatory processes. Frontally recorded CNV could be more strongly associated with task related cognitive aspects of the effort pool (conscious processing, decision making and reasoning), whereas central augmentation of negativity might be related to processes of motor preparation. In order to ascertain whether this assumption is valid, it would be appropriate to record negative cortical potentials using more electrode locations and to compare the potentials near the motor cortex with potentials at frontal locations.

As mentioned above, remarkable inter-individual variance in cortical slow wave patterns was observed. The wave pattern illustrated in Figure 4. resembles Klorman's results of developmental studies. He compared CNV's of 10-, 14- and 19-year-olds and found the similar early CNV (O-wave) in all developmental groups while the late CNV (E-wave) was apparent only in 14- and 19-year-olds (Klorman, 1975). Klorman suggested that the mechanisms contributing to the E-wave build-up were not mature in 10-year-olds. Taking into account the function of E-wave as psychomotor preparation, one might expect these subjects to differ in performance level from other subjects. This was in fact shown to be the case: this kind of wave pattern might be related to slow response speed. It may be further assumed that subjects of this study might be in a different phase of ongoing maturational process.

The planned age range in the forthcoming series of experiments is considerably wide, ranging from 8 to approximately 16 year-olds. For a developmental study, it should be assumed that the experimental variables have a similar effect on the effort pool in all age groups. On the other hand, based on Cohen (1973), it could be further assumed that a linear increase in CNV amplitude is observed throughout ages of 8 to 16 years. Therefore, the age groups should differ in CNV amplitudes due to maturational processes. However, one might question, whether the motivational factors have a similar effect on different age groups. This could mean, for example, that experimenter absence/presence and pay-off might have a different impact on the effort pool in different age groups. Age groups might not rate the reward equally and the presence of the experimenter is presumably different for adolescents than for children. Therefore, the impact on the effort pool might be incomparable. Similarly, the CPT design itself could pose differential challenges to different age groups.

In conclusion, the ambiguous ability of the CPT's to induce CNV in older healthy subjects might result in uncertainty in differentiating the clinical groups on this basis. The forthcoming series of experiments will shed light on this topic and facilitate firmer conclusions concerning differential characteristics of the CNV. The position adopted concerning the differential value of CNV does not exclude the potential of other measures to reveal critical issues in relation to deficits in information processing. On the contrary, this position underlines the importance of a multi-dimensional approach to the topic and suggests parallel analyses of additional measures (e.g. cardiac measures) with electrocortical measures.

In sum, this study investigated the effects of motivational factors on the compensatory functioning of the effort pool in Sanders' (1983) and Mulder's (1986) cognitive-energetical information processing model as a function of CNV-amplitude in healthy 8-9-year-olds. Motivational factors increased the amplitude of the negative cortical potentials, which can be viewed as reflecting increased resources of the effort pool. The relation between amplitude of the negative cortical potentials and the behavioral measures was unexpected to a certain degree: contrary to the literature, motivational factors were neither related to response speed, nor its variance. Instead, the accuracy of performance was increased during conditions in which effort's resources were manipulated, although the negative cortical potentials were not correlated with accuracy of responses. Therefore, the behavioral results in the present study leave room for interpretation and demand further study. Clearly, the overall results support the use of a multi-dimensional approach in order to untangle the compensatory functioning of effort and its deficits.

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