Proc. Colloque INSERM: Activités evoquees et leur conditionnement chez l'homme normal et en pathologie mentale, Tours, Sept. 1972. pp. 121-52

ON WHAT IS THE CONTINGENT NEGATIVE VARIATION (CNV) CONTINGENT IN REACTION-TIME EXPERIMENTS?

Risto NÄÄTÄNEN (1)
Institute for Perception TNO
Soesterberg, the Netherlands

I. INTRODUCTION

The basic experimental paradigm for development of the contingent negative variation (CNV) appears to involve that of a constant-foreperiod reaction-time experiment. In this task, a warning or a preparatory stimulus (S_1) is followed by an "imperative" stimulus (S_2), to which the subject makes a motor response. The CNV occurring in this experimental situation was already reported in the famous 1964-paper by Walter and his colleagues (1) and since then, this task was frequently used in slow-potential studies conducted also in other laboratories.

Irrespective of these research efforts and those involving different kinds of experimental setups, the psychological and behavioral significance of the CNV phenomenon is still

---

1 Supported by The Netherlands Organization for the Advancement of Pure Research (ZWO).
Present address: Institute of Psychology, University of Helsinki, Helsinki, Finland.

far from being clear and there is no reason herein to deliver the traditional long list of candidates for a psychological correlate of the CNV with which so many articles dealing with the phenomenon begin. My present purpose is to discuss the contribution coming from the reaction-time experiments of the CNV to our understanding of its psychological and behavioral significance. On what is it contingent in the reaction-time situation? Let us review recent experiments.

II. STUDIES OF THE CNV IN THE REACTION-TIME SITUATION

All the investigations on the relationship between the CNV and the reaction time report a CNV preceding the imperative stimulus (S_2) if a warning stimulus (S_1) was delivered. To use a relatively short, approximately one-second interstimulus interval and to instruct the subject to respond motorically as fast as possible to the second stimulus, is one of the most reliable ways to demonstrate the CNV phenomenon and one which usually produces a CNV of considerable size. Now, the question is what this slow negative potential signifies.

Naturally, it was first thought that this phenomenon probably is an electrophysiological sign of preparedness to react, and to clarify the issue, a considerable amount of research effort was launched at the relationship between the amplitude (sometimes area) of the CNV and the reaction time. As a result, many investigators reported a statistically significant relationship between the size of the CNV and the speed of the reaction.

Unfortunately, most of the significant relationships provided were rather indirect, coming from experiments in which the manipulation of a third variable either speeded up the response and amplified the CNV or slowed down the response and attenuated the CNV. To take an example, Irwin, Knott, McAdam and Rebert (2) were able to produce shortened reaction times and heightened CNV's by raising the intensity of the electical shock that served as S_2. Hillyard (3) remarks that "the incremented shock, however, may have caused the increase in CNV by one mechanism and the decrease of RT by a completely independent one, making the observed correlation 'spurious' (p. 356).

Rebert and Tecce (4) give the following list of experimental manipulations which alter the CNV or the RT and produce associated changes in the other variable:

- Distraction reduced the CNV and increased the reaction time and reward increased the CNV and decreased the reaction time (5);
- Strong shock increased the CNV and decreased the reaction time (2);
- Avoidable shock increased the CNV and decreased the reaction time (6);
- Drowsiness decreased the CNV and increased the reaction time (7);
- As interstimulus interval increased, the CNV decreased and the reaction time increased (8);
- Successful lobotomy produced an increased CNV and decreased the reaction time (9);

- Anxiety produces a smaller CNV and a longer reaction time (10);
- Altering nature of the interstimulus interval produced a smaller CNV and a slower reaction time (11);
- Subjects with a large CNV difference between speed and relax conditions also had large difference in the reaction time (12).

They have, however, found also many instances where experimental manipulations produce a dissociative change in the CNV and the reaction time (4).

A more direct approach to the problem can be found, for example, in an important and often cited work by Hillyard (3) which, according to Rebert and Tecce (4), includes ten out of the 19 correlation coefficients concerning the CNV - reaction-time relationship found by the authors in their literature survey. In Hillyard's study, five of the ten subjects used were reported to demonstrate a statistically significant negative correlation between the CNV amplitude and the RT. The author concludes that, under constant conditions, the CNV "can index a response-governing process that waxes and wanes spontaneously over periods of seconds and determines inverse changes in RT" (p. 357).

This conclusion possibly is optimistic for the following reasons. First, we should remark the very large range of reaction times of those subjects who showed significant correlations in this task which usually has a relatively small variance (13). This large variance apparently was due to the use of inexperienced subjects. One of the effects of practice in a performance task is a greatly reduced variance and presumably this reduction can mainly be attributed to the elimination of conspicuous failures, i.e., very long reaction times. These were frequent in the data of the five subjects showing significant correlations and a closer look on the data gives the impression that the statistical significance of the correlations is mainly resting on these extremely long reaction times connected with low CNVs. If only the normal range is examined, no CNV - reaction-time relationship seems to exist any more with two of the five subjects concerned and the statistical significance of the appearing tendency is in danger with the three other subjects (see figure 4 in Hillyard's article). The CNV cannot be considered an indicator of preparedness if the CNV is able to indicate only failures but is insensitive to the normal variation in the reaction time.

Another remark relates to the unexceptionally high frequency of the anticipatory reactions. In the data of two of the subjects showing the most convincing relationship between the CNV and the reaction time, approximately 15-30 % of all the responses were of anticipatory nature (<100 msec). Especially for naive subjects it is extremely unusual to react with less than 100 msec without anticipating. This naturally leads to the assumption that these data are not reaction-time - data. Instead these data to a great extent indicate the degree of success of the subject in trying to synchronize the response to S_1 with a delay somewhat longer than the S_1-S_2 interval.

According to Ollman and Billington (14), this kind of strategy is readily adopted by the subjects when short constant interstimulus intervals are used without catch trials. With a large percentage of anticipatory responses in an experimental session, even reaction times of normal length, according to Ollman and Billington, are no guarantee that the subject did not use an anticipatory strategy even at these trials. Thus Hillyard's data partially reflect a process different from getting prepared to respond which further complicates the interpretation of the significant correlations obtained. This study deserves, however, commendation for its careful control of ocular artifacts and of learning, habituation and fatigue effects.

In Waszak and Obrist's investigation (12), the anticipatory strategy was effectively prevented by introducing a disjunctive reaction task in which the imperative stimulus could be either positive (respond) or negative (do not respond). Thus, the subject had no advance knowledge of whether a response was required or not. Also their subjects were more practiced than in the afore-reviewed study. Using within-subject data, the former investigators compared only ten fastest reaction times to ten slowest reaction times leaving some 25 intermediate ones outside the analysis, a disadvantage in comparison to Hillyard's work in which all the reaction times obtained entered into the statistical analysis. Now the possible too fast and too slow responses became overrepresented. It is difficult to estimate the significance of this effect as neither the standard deviations nor the ranges of the reaction times were indicated. In any case, a statistically significant negative relationship between the variables was reported.

Unfortunately, no control against the possibility of a spurious relationship induced by a third factor affecting both variables during the course of the experimental session was reported - some amount of practice is no guarantee in this respect. No information involving the changes of the reaction time and the CNV during the course of the session was given. Moreover, the kind of the experimental task used, the disjunctive reaction task, also raises the question of the possible effect of the right and wrong guesses on the relationship established. It is well established that at some trials the subject feels the possibility of the Yes-stimulus more probable than at some other trials - this is, among other factors, determined by the stimulus categories of the preceding trials. A high subjective probability, or expectancy, of the Yes-stimulus (the significant stimulus requiring the motor response) presumably induces a high CNV and is also known to expedite the response (15-17). Similarly, a low subjective probability is likely to be accompanied by a low CNV and a slow reaction time.

A very interesting subsidiary observation involving a much higher amplitude of the positive component of the evoked response to the No-Response S_2 at a latency of approximately

300-400 msec, compared to that associated with the Yes-Response S_2, was reported. It was mentioned, however, that the latter was much broader. Maybe this amplitude difference can partially be explained by the higher degree of time-lockedness of the positive deflection after the No-Response S_2, owing to the presumably smaller temporal variance of neural events in this case.

Connor and Lang (1969), in a study involving simultaneous changes of the heart rate and the disjunctive or the simple reaction during a fore-period of 5.76 sec (from the offset of S_1 with a duration of 1.92 sec), also studied within-subject relationship between the CNV amplitude and the reaction time, by averaging the CNV over five fast and five slow trials in each condition for each subject. The main effect of the within-subject reaction time was significant for the CNV.

Many of the remarks made with respect to the works reviewed above also apply to this investigation. No information was provided as to the variation of reaction times and we are not able, therefore, to estimate if it were appropriate to consider the relationship reported partially an effect of an "over-stretched" performance variable, as described above, which possibility is enhanced by the use of relatively inexperienced subjects(one practice session)and the comparison of the (few) trials with most deviating - in either direction - level of performance. No check was reported with respect to the possibility of comparing groups of trials from different phases of the experimental session when the five fast and the five slow reaction times were compared. Moreover, in this part of the investigation, the eye movements were not recorded and the number of the anticipatory responses (both reaction tasks) and of the wrong responses of the disjunctive reaction-time task was not reported. The frequency of the anticipatory responses must have been relatively low, however, owing to the use of a rather long interstimulus interval (5.76 sec).

In their important study on the nature of the psychological correlate of the CNV phenomenon by means of distraction introduced prior to or within S_1-S_2 interval, Tecce and Scheff (5) correlated the CNV amplitude and the simple reaction time within their no-distraction trials using an interstimulus interval of 1.5 sec. For each subject, (single) CNVs for the faster and slower halves of all reaction times were grouped to yield two averaged CNVs - one for the faster and one for the slower reaction times.

No information regarding the relative positions of the fast and slow reaction times within the experimental session was provided, unfortunately. If there were systematic differences in this respect, then it would be possible that the relationship obtained between the two variables in a matter of fact is a reflection of their dependence on a third variable. This possibility is increased by their probable use of inexperienced subjects - the authors make no mention as to the degree of training the subjects were given before experimental session. The use of inexperienced subjects is also apt to increase the range of reaction times by introducing "failures", occasional exceptionally long reaction times, a point discussed earlier in the present paper. Unfortunately, reaction times, their means, standard deviations and ranges, were not reported.

Another remark relates to the recording of eye movements which was done only for four subjects.

There are also studies in which no significant correlation between the CNV and reaction time was reported. The principal goal in the investigation by Peters, Knott, Miller, van Veen and Cohen (11) was to study the effect of the termination of the imperative stimulus by the subject's own response (vs. automatic termination) in a simple reaction-time situation. The constant interstimulus interval used was 1.5 sec. The CNVs developing during the foreperiod were compared between two conditions: the imperative stimulus is (a) a single flash; (b) a train of flashes (lasting maximally up to 600 msec) terminated by the subject's response if given within 600 msec from the imperative stimulus. It was found that the amplitude of the CNV was remarkably larger under the latter condition which result was suggested to reflect differential levels of motivation.

As a side result, no significant across-subjects correlation between the CNV and the reaction time was reported (Spearman's rank-order correlation) within each condition but within-subjects correlations were not calculated. The correlation between the reaction time and the trial number during the session were also unreported as well as the range and the standard deviation of the reaction times. No information involving anticipatory responses was provided. The reader is somewhat puzzled by the great difference in reaction times between the conditions: the single imperative stimulus - 514 msec; the repetitive imperative stimulus - 224 msec. Eye-movement artifacts were carefully controlled in this study.

In an early investigation aiming at demonstrating the importance of motivational factors in the genesis of the CNV, Irwin, Knott, McAdam and Rebert (2) reported having found no statistically significant correlation between the CNV and the reaction time in their first experiment.[1] This observation relates to an experimental condition in which a tone from the right-hand loud speaker was followed by a visual stimulus at a latency of 1500 msec. (The subjects were instructed not to respond if the first signal was given by the left-hand loud speaker.) The data for responses to the right signal were

---

[1] In the summary of their paper, Irwin et al., referring to their second experiment, write that "although reaction times were significantly shorter to the strong shock, a significant correlation between CNV magnitude and reaction time could be demonstrated only within the weak shock condition". There is no additional information on this specific point elsewhere in the paper, however.

analyzed to compare, for each subject, the amplitude of the CNV of the ten fastest and ten slowest trials. The mean difference was not significant (related t = 1.728, d.f. = 7, $p < 0.05$).

Unfortunately, the eye movements were not recorded in this study. Additionally, no information was provided involving the possible changes in the reaction time during the experimental condition concerned.

Especially interesting data were obtained in this investigation by recording the EMG of the responding hand (the motor point of the flexors of the fourth finger which was used to perform the key-press response) simultaneously with the CNV. In the above described condition, it was scored in terms of detectable increases in activity during the foreperiod of each reaction time trial. When the warning signal was on right (indicating that a response is to be given to the soon appearing flash), about a half of the trials showed anticipatory EMG activity. When the signal was on left (non-response indicated), only 1.6 % of the trials showed anticipatory EMG activity. The difference was significant.

For each of seven subjects the mean amplitude of the CNV during trials which showed EMG activity was compared with the mean shift on an equal number of randomly chosen trials on which no foreperiod EMG activity occurred. (This was done only for trials when the warning signal was on the right, as there were too few trials showing EMG acticity when the tone was on the left to obtain a meaningful average.) The difference was not significant. The mean reaction time on trials during which increased EMG activity occurred did not differ significantly from that on trials during which no increase occurred.

In addition to these more specific remarks made in connection to the investigations reviewed, the following observations appear to be relevant with respect to most of these studies:

a) The averaged nature of the data resulting in loss in information to some unknown degree;

b) If a statistically significant relationship was reported, it usually reached only the .05 risk level;

c) The CNV amplitude correlated with the reaction time often was the highest CNV amplitude during the S_1-S_2 interval. This is, of course, a measure highly vulnerable to the contaminating effect of noise. Moreover, it seems inappropriate to use this measure involving remarkably varying latencies as the only CNV measure in correlating the size of the CNV with a performance measure taken at a fixed latency (at S_2 moment). This CNV measure should be replaced or compensated by amplitude measurements at the moment of performance (e.g., five equi-spaced amplitude measurements within the last 100 msec before S_2). If the CNV is an indicator of expectancy then it is not only important to have a high CNV (somewhere) between S_1 and S_2 but also to have it at the right moment.

In Soesterberg, we have recently conducted two experiments (18, 19) on the relationship between the CNV and the reaction time. In the first study, four constant interstimulus intervals, 200, 400, 1000 and 2000 msec, were used. The intertrial interval (S_1-S_1) was a constant interval of 6.2 sec. Four highly experienced subjects were run in two sessions. The EEG was recorded over the vertex and the eye movements from above and below the right eye.

The warning (S_1) - a horizontal slash - and the imperative signal (S_2) - an H or an X, in a random order - were presented on a nixie-tube display. The subject was seated in front of the nixie-tube display fixating on it and keeping his left index finger on the left key and his right index finger on the right key. He was instructed to press the left key when the H and the right key when the X was presented.

Because the vertex negativity was expected to develop already <u>before</u> S_1, the CNV was measured within two time ranges (see Fig. 1): a) the slow negative potential occurring before S_1, relative to the base-line (around 1 sec before S_1; see later), herein called CNV_1 and b) the "traditional" CNV, the vertex negativity at S_2 relative to that at S_1, herein called CNV_2. The negativity at S_2 was also referred to the baseline, i.e., the CNV_1 amplitude was added to the CNV_2 amplitude. This measure is hereincalled CNV_{1+2}. The baseline and the negativity at S_1 (S_1 - level) were obtained by averaging 5 equispaced points (40 msec apart) under the periods 960-800 and 160-0 msec before S_1, respectively. The slow-potential change at S_2 was measured by averaging 5 equispaced points (40 msec apart) under the last 160 msec preceding S_2 with the interstimulus intervals of 1000 and 2000 msec. For the 400-msec interstimulus interval, the 5 equispaced points (20 msec apart) were taken during the last 80 msec preceding S_2, in order to reduce the contaminating effect of the potential evoked by S_1 on the amplitude measurement of CNV_2.

This way of measurement was not possible with respect to interstimulus interval of 200 msec, because the vertex potential evoked by S_1 was superimposed on CNV_2. Therefore the average of the negativity of the peaks of N_1 and P_2 related to S_1-level was taken as a measure for CNV_2. This way of measurement was based upon the assumption that without any CNV development the peak of N_1 would be roughly as much higher the S_1 level than the peak of P_2 would be below it.[1] As the latency of the peak of N_1 generally varied between 180-200 msec and that of the peak of P_2 between 200-250 msec the latencies of measurements corresponded rather well to the latency of S_2.

To investigate the development of the CNV_2, the amplitudes around the following latencies after S_1 were measured: 500 and 750 msec for the interstimulus interval of 1000 msec and 500, 1000, 1500 and 1750 msec for the interstimulus interval of 2000 msec; an average of 5 equispaced (40 msec) points were taken around each of these latencies.

---

[1] The validity of this assumption was tested in the 2000-msec condition in which no CNV could be detected within the first 500 msec after S_1. The peaks of N_1 and P_2 of the potential elicited by S_1 were on an average 2.95 µV more negative and 5.52 µV more positive than the S_1-level, respectively. Thus, our manner of measurement of CNV for the interstimulus interval of 200 msec does not seem at least to favor the magnitude of the CNV_2.

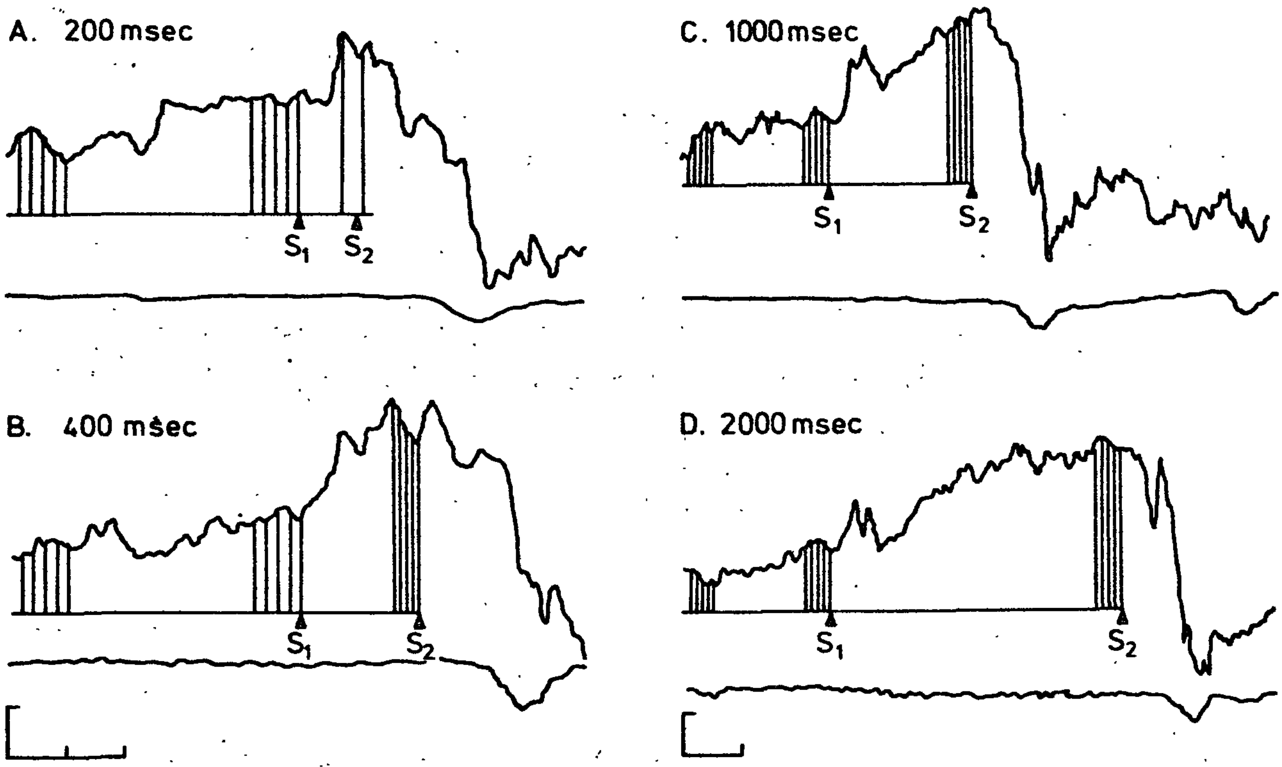

Fig. 1 - Vertex (upper trace) and eye potentials (lower trace) of one subject, averaged over the first 16 trials of the 2nd series of the 2nd session with each inter-stimulus interval . Upward deflection indicates negativity at the vertex or superior eye electrode. The vertical lines in the graphs illustrate the manner of measuring the CNV amplitudes. Calibrations: vertcal bar EEG = 10 µV, EOG = 100 µV; horizontal bar = 400 msec.

Also the peak-to-peak amplitudes P_1-N_1 and N_1-P_2 were measured for potentials elicited by S_1. Finally, several correlations between CNV and reaction time were computed. Not only averaged data were utilized, but also single-trial data. By correlating single-trial data measured within the same block of 35 trials, i.e. within a short time range (ca. 3.5 min), the possible effect of long-term changes in the state of the subject on the correlation coefficient was prevented.

Typical results are illustrated in Fig. 1. Slow negative

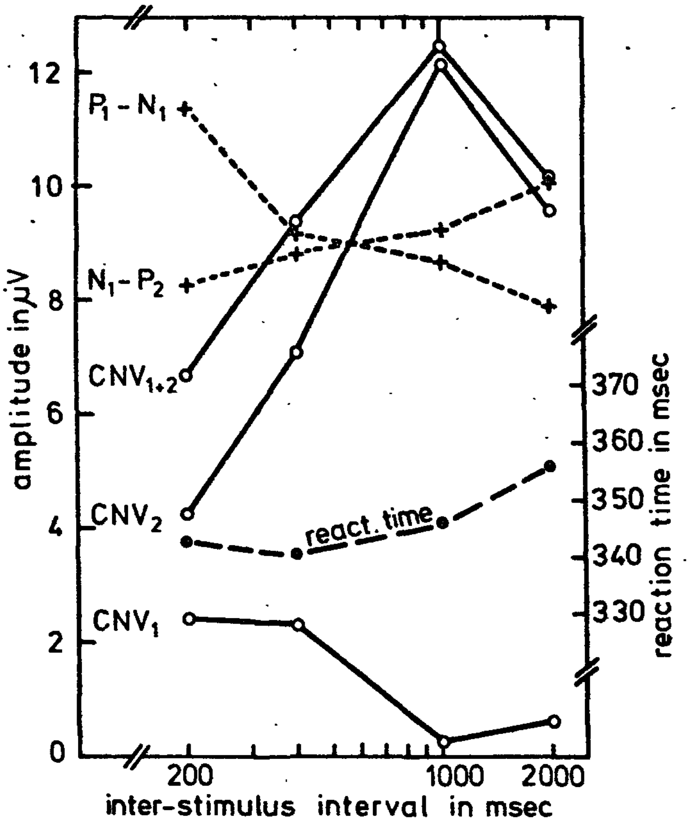

Fig. 2 - Mean amplitudes of CNV_1, CNV_2 and CNV_{1+2}, mean P_1-N_1 and N_1-P_2 amplitudes of the vertex potential evoked by S_1 and the reaction time as a function of the interstimulus interval.

potentials could generally be observed between S_1 and S_2. With the shorter interstimulus intervals there was considerable vertex negativity already before S_1 (CNV_1).

In Fig. 2 variables CNV_1, CNV_2, CNV_{1+2}, reaction time, P_1-N_1 and N -P_2 are plotted as a function of the interstimulus interval across subjects.

The product-moment correlation coefficients computed between mean CNV_1, CNV_2, CNV_{1+2} and the median reaction time are presented in Table I. In general, the correlations between

TABLE I. Product-moment correlations between CNV_1, CNV_{1+2} and median reaction time given separately for each inter-stimulus interval (N = 32). (From Gaillard and Näätänen, 1972)

ISI (msec)	CNV_1	CNV_2	CNV_{1+2}
200	-.24	-.03	-.18
400	-.09	-.43xx	-.49xx
1000	-.09	-.40x	-.44xx
2000	-.12	-.45xx	-.42xx

x $p < .05$
xx $p < .01$

TABLE II. Product-moment correlations between CNV_2 and median reaction time given separately for each inter-stimulus interval and the corresponding correlations when sessions, blocks and subjects were partialized out (N = 32). (From Gaillard and Näätänen, 1972)

	ISI 400 msec	ISI 1000 msec	ISI 2000 msec	Across ISIs
CNV_2 x RT	-.43xx	-.40x	-.45xx	-.40xx
CNV_2 x RT, sessions	-.39x	-.39x	-.46xx	-.38xx
CNV_2 x RT, sessions x blocks	-.42x	-.39x	-.46xx	-.38xx
CNV_2 x RT, sessions x blocks x subjects	-.23	-.27	-.06	-.19x

x $p < 0.05$
xx $p < 0.01$

the reaction time and CNV_{1+2} were higher than those between the reaction time and CNV_2 alone; this may indicate that the vertex negativity before S_1 has an influence on reaction time.

In order to estimate the influence of sessions, blocks and subjects on the significant correlations between CNV_2 and the reaction time, partial correlations were computed. These correlations give the correlations between the CNV and the reaction time, when the effects of sessions, blocks and subjects are kept constant. Table II shows that when the effects of sessions and blocks were partialized out the correlations were unaffected; when, however, the influence of subjects was held constant the correlations became insignificant. With the interstimulus interval of 2000 msec the influence of subjects was especially strong. This subject-effect agrees with the results of Hillyard and Galambos (20), who found a significant negative correlation between a subject's average CNV and his reaction time.

The CNV amplitudes of two subjects for the interstimulus interval of 1000 msec were measured from the single-trial records (see Fig. 3).

The eight correlations, each of which were computed over 29-34 consecutive trials of a block, varied between r=+.24 and r=-.47; only one of them (-.47) was statistically significant.

Figure 4 shows that the CNV starts already before S_1 with the short interstimulus intervals, whereas with the interstimulus interval of 2000 msec only one of the four subjects showed CNV development at 500 msec after S_1 (one-sided t-test, $p < 0.01$). With the short interstimulus intervals the CNV_2

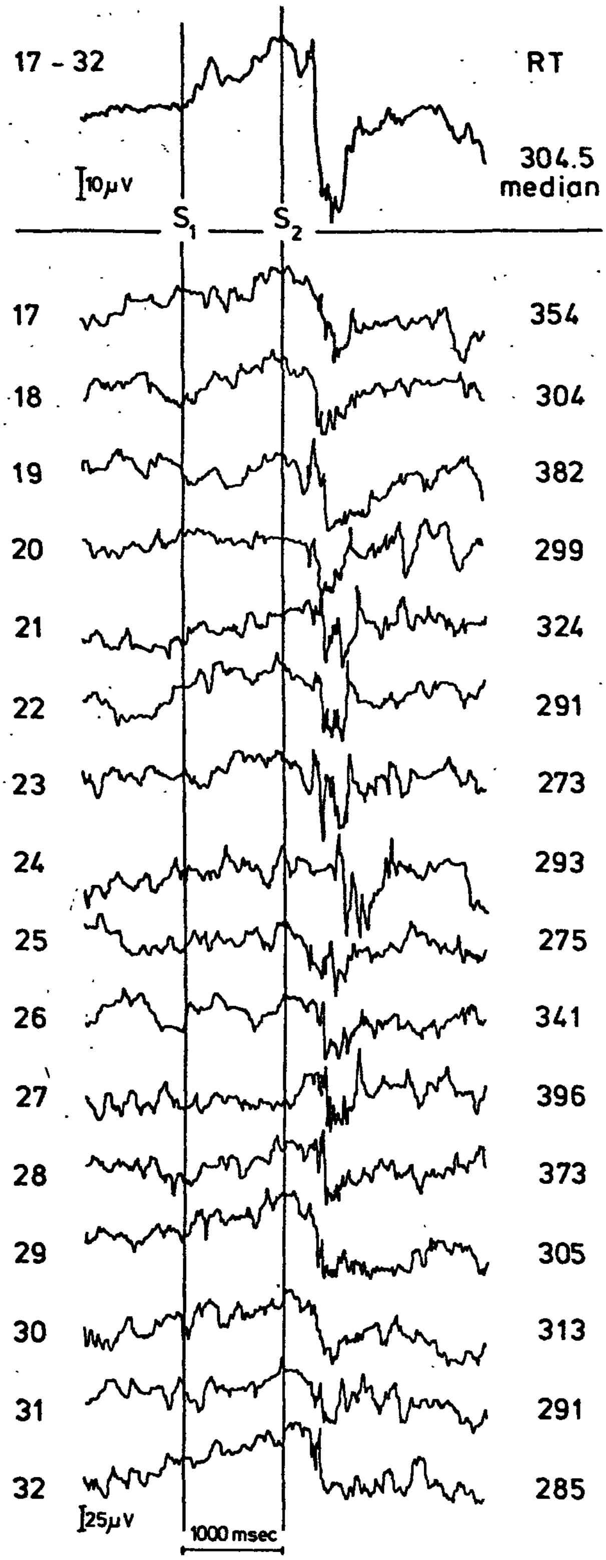

Fig. 3 - Upper trace: Vertex potential averaged over the 17th-32nd trial with 1000-msec interstimulus interval of the 2nd series of the 2nd session of one subject. Lower traces: Single vertex records of the averaged record represented in the upper trace.

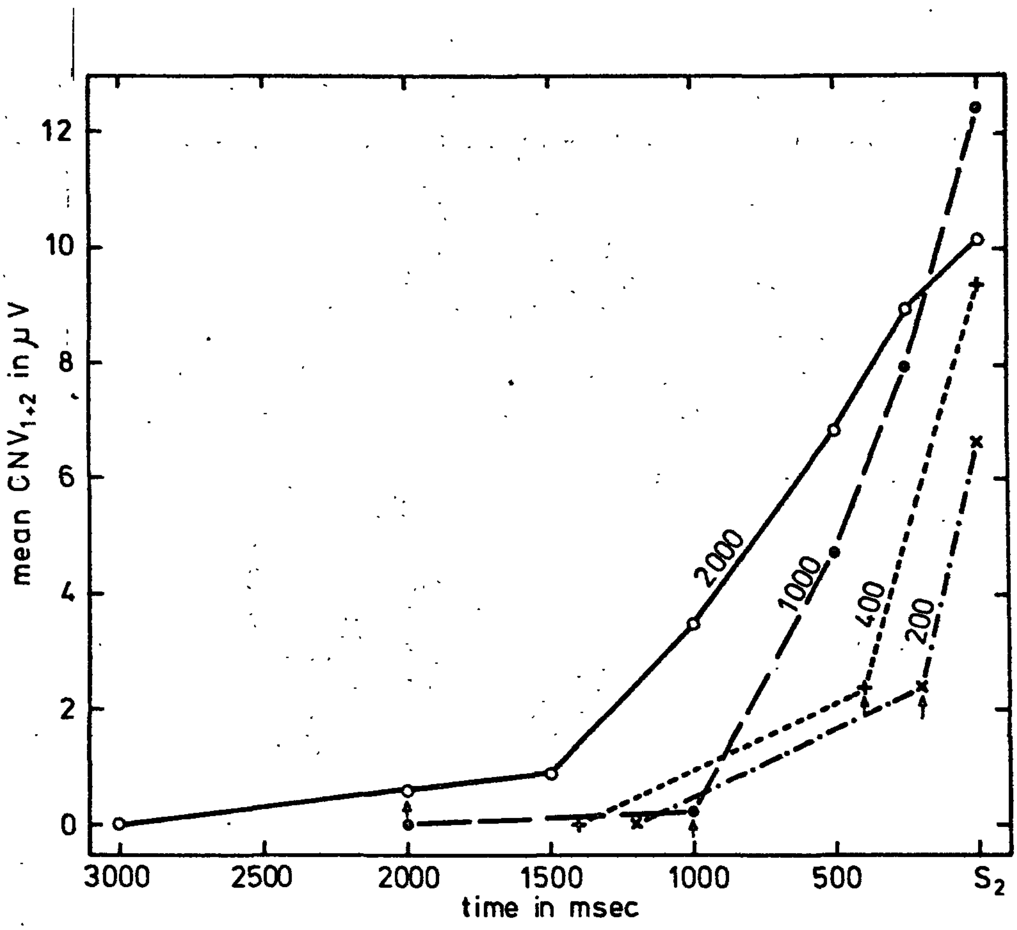

Fig. 4 - The rise of CNV in time before and during each of the four interstimulus intervals. The arrows represent the moment of presentation of S_1. Every point represents a mean of 32 averages, each based on 16 trials.

developed more abruptly after S_1 than with the long interstimulus intervals.

We concluded that the relationship between preparedness and the CNV seems rather complicated: During each interstimulus interval studied, the CNV grows throughout the entire period, as preparedness apparently also does. Also the slope of the CNV is the more abrupt, the shorter the interstimulus interval; this again being understandable when the CNV is thought to reflect preparedness. When, however, comparisons of the CNV amplitudes at the end of the interstimulus interval are made between the interstimulus intervals, the CNV does not seem to reflect preparedness, or it may be that it reflects also other aspects than preparedness of the state of the organism preparing to react to a stimulus (21). This conclusion is reached also when the correlations between the CNV and the reaction time calculated separately for each interstimulus interval are examined: these correlations were weak, and when the subject-effect was eliminated they became insignificant.

In our most recent study (19), the relationship between the CNV and the (simple) reaction time was our specific scope. Using three highly experienced subjects and recording the EEG from the vertex (C_z) and frontal (F_z) electrode (time-constant 6 sec), we gave to our subjects 1000 S_1-S_2 pairs with a constant interstimulus interval of one second. In the first session, no catch trials were used; in the second session randomized catch trials were introduced to a proportion of one to ten. Under the latter condition, the reaction time stayed at a constant level through the whole session and anticipatory responses were rare.

The single CNVs were measured by means of a PDP-8 computer. Five different measures were taken from each single CNV after eliminating the trials contaminated by eye movements: (a) the negativity of the period 500-392 msec before S_1 relative to the baseline, 108-0 msec before S_1; (b) the baseline relative to the electrical zero of the system; (c-e) the negativity of the period 500-608, 772-880, 892-1000 msec from S_1 relative to the baseline, respectively. Each measure was the average of ten equispaced points.

Table III gives the number of statistically significant and insignificant correlations between the CNV_{1000} (892-1000 msec from S_1 relative to the baseline; 10 equispaced points) and the reaction time within blocks of 32 consecutive single trials, separately for the vertex and frontal data. It is evident that the significant correlations were only accidental; no relationship between the CNV and the reaction time seems to exist.

Table IV gives the correlation coefficients between the different amplitudes (a-e) of the vertex CNV and the corresponding reaction time, separately for the first quarter (approximating the normal duration of a reaction-time experiment) of the session and for the whole session. The single-trial coefficients for the Quarter I were calculated over 208 consecutive single trials; for the whole session usually over 832 consecutive single trials. The coefficients involving the means (of 16 consecutive single trials) for Quarter I were calculated over 13 means; for the whole session usually over 52 means. Table V gives the respective correlation coefficients for the frontal data. Again we conclude that the statistically significant correlations were only accidental (22 of them were negative, 15 positive, the vertex and frontal data taken together).

No habituation in the amplitude of the CNV was observed.

TABLE III. The number of statistically significant and insignificant correlations ($p < 0.05$) between the CNV_{1000} and the reaction time within a block of 32 single consecutive trials according to one- and two-tailed product-moment correlation methods. The upper number refers to the vertex data, the lower to the frontal data (From Näätänen and Gaillard, 1972).

		NO CATCH TRIALS			CATCH TRIALS			
SUBJECT	CORRELATION	1	2	3	1	2	3	TOTAL
positive	one-sided	2 -	- 2	- -	- -	- 1	1 -	3 3
positive	two-sided	- 2	1 1	1 -	2 -	1 1	1 -	6 4
negative	one-sided	1 -	- -	1 -	1 -	1 -	- -	4 0
negative	two-sided	1 1	1 2	1 1	- -	- 1	- -	3 5
non-significant		22 23	24 21	15 17	23 26	24 23	24 26	132 136

TABLE IV. The correlation coefficients between the amplitude of the vertex CNV and the corresponding reaction time, given separately for each subject and condition. In each group of 5 coefficients from top to bottom, the reaction time correlated with: (1) the negativity of the period 500-392 msec before S_1 relative to the baseline; (2) the baseline; (3-5) the negativity of the period 500-608, 772-880, 892-1000 msec from S_1 relative to the baseline, respectively. Correlation coefficients are separately given for the first quarter of the session and for the whole session (From Näätänen and Gaillard, 1972).

	NO CATCH TRIALS						CATCH TRIALS					
	Subject 1		Subject 2		Subject 3		Subject 1		Subject 2		Subject 3	
	Single trials	Means	Single trials	Means	Single trials	Means	Single trials	Means	Single trials	Means	Single trials	Means
QUARTER I	-.07	-.47x	.07	.47x	.13x	.36	.06	.11	-.01	-.04	-.14x	-.30
	-.03	.32	.06	.34	-.05	-.35	-.10	-.26	-.04	-.58x	.12x	.55x
	-.19xx	-.45	.00	.54x	.05	.09	.01	.09	-.03	.21	-.16xx	-.35
	-.16xx	-.26	-.09	.22	-.15x	-.33	.05	-.16	.02	.34	-.06	-.41
	-.16xx	-.28	-.15x	.04	-.07	-.09	.10	-.21	.04	.56x	-.04	-.38
WHOLE SESSION	-.03	.00	.01	-.04	-.01	.19	.00	.03	.00	.03	-.05	-.16
	-.02	.04	.06	.06	.02	-.14	-.05	.04	.00	-.31	.03	.15
	-.01	-.36xx	-.02	-.14	-.06	.03	-.02	-.15	-.01	.10	-.08x	-.09
	-.06	-.51xx	-.05	-.08	-.09	-.36x	.01	-.10	.00	.24x	-.02	-.13
	.01	-.22	-.08x	-.14	-.02	-.16	.03	-.18	.01	.27x	.01	-.03

x $p < 0.05$, xx $p < 0.01$

TABLE V. The correlation coefficients between the amplitude of the <u>frontal</u> CNV and the corresponding reaction time, given separately for each subject and condition. In each group of 5 coefficients from top to bottom, the reaction time correlated with: (1) the negativity of the period 500-392 msec before S_1 relative to the baseline; (2) the baseline; (3-5) the negativity of the period 500-608, 772-880, 892-1000 msec from S_1 relative to the baseline, respectively. Correlation coefficients are separately given for the first quarter of the session and for the whole session (From Näätänen and Gaillard, 1972).

	NO CATCH TRIALS						CATCH TRIALS					
	Subject 1		Subject 2		Subject 3		Subject 1		Subject 2		Subject 3	
	Single trials	Means	Single trials	Means	Single trials	Means	Single trials	Means	Single trials	Means	Single trials	Means
QUARTER I	-.07	.09	.09	.22	.09	.31	.07	.04	.02	.00	-.15x	-.10
	.05	.21	.07	.30	-.03	-.22	-.01	-.36	.09	.42	.12x	.38
	-.16xx	-.30	.04	.53x	-.03	.11	.00	-.11	.04	.50x	-.10	-.07
	-.12x	.05	-.03	.31	-.05	-.09	.03	-.26	.05	.55x	-.11x	-.14
	-.11x	.05	-.08	-.19	.04	.21	.04	-.34	.07	.66x	-.09	-.20
WHOLE SESSION	-.03	.11	.00	-.13	-.04	.12	.03	.00	.04	-.01	-.05	-.17
	-.02	.15	.08x	.04	.04	.01	.01	.03	.04	.13	.04	.20
	-.05	-.37xx	.01	.01	-.04	.08	-.01	-.13	.00	.17	-.07x	-.08
	-.05	-.41xx	.00	.15	-.09	-.19	.01	-.05	-.01	.30x	-.04	-.11
	.00	-.13	-.01	.09	-.03	.00	.01	-.13	.00	.32xx	-.01	.03

x $p < 0.05$
xx $p < 0.01$

III. DISCUSSION AND CONCLUSIONS

On the basis of this literature review and our own experiments it seems to me that preparedness, as indicated by the reaction time, is not correlated with the amplitude of the CNV. This conclusion is in perfect agreement with the results of Dr. McCallum reported here (22).

A few words about another - and persistent - candidate for the psychological correlate of the CNV, expectancy. I want to stress the word "another" as many people speak about preparedness and expectancy as if these were equivalent concepts. For expectancy, I would like to reserve its original associative or cognitive meaning of subjective probability in which case, as far as the reaction-time performance is concerned, expectancy would be one determinant of readiness together with many other factors (15, 16). To go back to the specific topic of the present paper, this would mean that the nonexistent relationship between the CNV and the reaction time, which dropped preparedness out from the group of possible correlates for the CNV, does not necessarily do the same with respect to expectancy. There are, however, some other data inconsistent with the idea that expectancy is the correlate for the CNV in the reaction time situation, namely:

(a) The CNV starts and reaches its amplitude too late (see, e.g., Fig. 4) to be a correlate of expectancy under certain conditions. The subject's time-uncertainty of the stimulus, to use Klemmer's (23) concept, is understood to be at its minimum, i.e., expectancy at its maximum, at very short interstimulus intervals from 200 to 400 msec, when the

CNV is still very low or completely lacking.

(b) Many workers have remarked a rectangular form of the CNV, i.e., a rapid rise and a long flat part in the reaction-time condition in many subjects (3, 24). The CNV seems to reach its maximal amplitude often in an early phase of the interstimulus interval when it is not yet reasonable to assume that the subject really is expecting the stimulus and he would react very slowly if the stimulus were presented as early as this.

Thus, we are led to the conclusion that expectancy is not, at least alone, the correlate of the CNV in the reaction-time situation. Now it seems necessary, in the present state of knowledge, to consider more general - and also more vague - concepts in our search for a psychological or behavioral correlate for the CNV appearing during the foreperiod of the reaction-time situation. The concept of attention, especially attention directed to the task, selective attention, is generally regarded as a good candidate for this purpose and there appear to be no data reported in the CNV-reaction time literature in disagreement with this proposition. On the other hand, compared to the two rejected concepts, expectancy and preparedness, attention has the drawback of vagueness and considerably greater difficulties of measurement.

So we can conclude that studies on the relationship between the CNV and the reaction time have not found the psychological correlate of the CNV.

It seems well established that the CNV to some extent is a relatively general activation phenomenon (25) and in this light the weak or non-existent correlations between the CNV and the reaction time are in agreement with the many results involving non-existent or only weak correlations between the reaction time and several measures of relatively nonspecific activation of the central nervous system, such as the EEG-frequency, EEG-amplitude and α-blocking (4). The electrophysiological correlates of the reaction time will probably be provided by more specific processes than is the CNV recorded over the scalp (26, 27).

IV. SUMMARY

The purpose of this paper was to discuss the contribution of the CNV experiments of the reaction time to our understanding of the psychological or behavioral significance of the CNV. The literature on the relationship between the CNV and reaction time was reviewed and the conclusion reached that the CNV is not the correlate of preparedness, as indicated by the reaction time. Dissociation phenomena also between the CNV and expectancy were discussed. It was concluded that the investigations on the relationship between the CNV and the reaction time have not found the psychological or behavioral correlate phenomenon of the CNV.

REFERENCES

(1) WALTER, W.G., COOPER, R., ALDRIDGE, V.J., McCALLUM, W.C., & WINTER, A.L., 1964. - Contingent negative variation: An electric sign of sensorimotor association and expectancy in the human brain. Nature 203, 380-384.

(2) IRWIN, D.A., KNOTT, J.R., McADAM, D.W., & REBERT, C.S., 1966. - Motivational determinants of the "contingent negative variation." Electroencephalography and Clinical Neurophysiology 21, 538-543.

(3) HILLYARD, S.A., 1969. - Relationships between the contingent negative variation (CNV) and reaction time. Physiology and Behavior 4, 351-357.

(4) REBERT, C.S., TECCE, J.J., 1971. - A summary of CNV and reaction time. Proceedings of II international congress on the contingent negative variation, 71-73.

(5) TECCE, J.J., & SCHEFF, N.M., 1969. - Attention reduction and suppressed direct-current potentials in the human brain. Science 164, 331-333.

(6) CANT, B.R., & BICKFORD, R.G., 1967. - The effect of motivation on the contingent negative variation (CNV). Electroencephalography and Clinical Neurophysiology 23, 594.

(7) NAITOH, P., JOHNSON, L.C., LUBIN, A., 1971. - Modification of surface negative slow potential (CNV) in the human brain after total sleep loss. Electroenceph. clin. Neurophysiol. 30, 17-22.

(8) McADAM, D.W., KNOTT, J.R., & REBERT, C.S., 1969. - Cortical slow potential changes in man related to interstimulus interval and to pre-trial prediction of interstimulus interval. Psychophysiology 5, 349-358.

(9) WALTER, W.G., 1966. - Electrophysiologic contributions to psychiatric therapy. Current Psychiatric Therapies 6, 13-25.

(10) McCALLUM, W.C., WALTER, W.G., 1968. - The effects of attention and distraction on the contingent negative variation in normal and neurotic subjects. Electroenceph. clin. Neurophysiol. 25, 319-329.

(11) PETERS, J.F., KNOTT, J.R., MILLER, L.H., VAN VEEN, W.J., & COHEN, S.I., 1970. - Response variables and magnitude of the contingent negative variation. Electoencephalography and Clinical Neuropsysiology 29, 608-611.

(12) WASZAK, M., & OBRIST, W.D., 1969. - Relationship of slow potential changes to response speed and motivation in man. Electroencephalography and Clinical Neurophysiology 27, 113-120.

(13) WOODWORTH, R.S., & SCHLOSBERG, H., 1954. - Experimental psychology. (Rev. ed.) New York: Holt.

(14) OLLMAN, R.T., & BILLINGTON, M.J., 1972. - The deadline model for simple reaction times. Cognitive Psychology 3, 311-336.

(15) NÄÄTÄNEN, R., 1970. - The diminishing time-uncertainty with the lapse of time after the warning signal in reaction-time experiments with varying fore periods. Acta Psychologica 33, 178-192.

(16) NÄÄTÄNEN, R., 1971. - Non-aging foreperiods and simple reaction time. Acta Psychologica 35, 316-327.

(17) NÄÄTÄNEN, R., 1972. - Time uncertainty and occurrence uncertainty of the stimulus in simple reaction time task. Acta Psychologica 36, (in press).

(18) GAILLARD, A.W. & NÄÄTÄNEN, R., 1972. - Slow potential changes and choice reaction time as a function of interstimulus interval (unpublished).

(19) NÄÄTÄNEN, R. & GAILLARD, A.W., 1972. - The contingent negative variation (CNV) and the simple reaction time in a prolonged performance (unpublished).

(20) HILLYARD, S.A. & GALAMBOS, R., 1967. - Effects of stimulus and response contingencies on a surface negative slow potential shift in man. Electroencephalography and Clinical Neurophysiology, 22, 297-304.

(21) NÄÄTÄNEN, R., 1972. - The inverted-U relationship between activation and performance - A critical review. In: S. Kornblum (Ed.) Proceedings of Fourth International Symposium on Attention and Performance. Boulder, Colorado. August 1971. Academic Press, 155-174 (in press).

(22) McCALLUM, C., 1972. - (This symposium.)

(23) KLEMMER, E.T., 1956. - Time uncertainty in simple reaction time. Journal of Experimental Psychology 51, 179-184.

(24) TECCE, J.J., 1972. - Contingent negative variation (CNV) and psychological processes in man. Psychological Bulletin 77, 73-108.

(25) NÄÄTÄNEN, R., 1967. - Selective attention and evoked potentials. Annales Academiae Scientiarum Fennicae 151, 1-226.

(26) VAUGHAN, H.G., 1969. - The relationship of brain activity to scalp recordings of event-related potentials. In E. Donchin & D.B. Lindsley (Eds.) Average evoked potentials; methods, results and evaluations. Washington D.C.: U.S. Government Printing Office.

(27) VAUGHAN, H.G., 1972. - (This symposium.)

RESUME

EN QUOI LA VARIATION CONTINGENTE NEGATIVE
EST-ELLE CONTINGENTE DANS LES EXPERIENCES DE TEMPS DE REACTION

L'étude poursuivie ici porte sur la variation contingente négative, onde lente qui apparait sur la région antérieure du scalp au cours de situations généralement considérées comme supposant une anticipation. Dans le protocole expérimental qui les fait apparaitre, le sujet a pour tâche d'interrompre immédiatement une stimulation répétitive dès son début. Une telle situation est donc très proche de celle des expériences de temps de réaction étudié en psychologie. Pour préparer le sujet à cette tâche un signal précède la stimulation d'une seconde. Dans l'intervalle entre le signal et la stimulation on enregistre alors l'onde lente, variation contingente négative (V.C.N.) appelée encore par WG. WALTER "onde d'attente, onde d'expectative" car elle précède la stimulation et le mouvement à effectuer.

Le but de cette étude est de discuter l'apport des expériences, étudiant parallèlement la variation contingente négative et le temps de réaction, à la compréhension de la signification de cette onde lente envisagée dans une perspective aussi bien psychologique que comportementale. Les résultats aboutissent à cette conclusion que la variation contingente négative n'est pas en relation avec la préparation motrice, telle qu'elle est indiquée par le temps de réaction. Des phénomènes de dissociation entre la variation contingente négative et l'expectative sont discutés.

La conclusion est que les investigations sur les relations entre variation contingente négative et temps de réaction n'ont pas mis en évidence les correspondances psychologiques ou comportementales de ce phénomène.