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RELATIONSHIP BETWEEN AROUSAL AND ACTIVATION, AND SENSATION SEEKING

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Summary—In previous experiments we tested the paradigm (De Brabander, *Perceptual and Motor Skills*, *69*, 75–82, 1988) that phasic arousal reactions are reflected by retarded reactions after an unexpected preparatory signal in a visuospatial (right hemisphere) discrimination reaction time task. Phasic activation responses are shown by accelerated reactions after the preparatory signals in a semantic (left hemisphere) task. In the present experiment the results do again validate the paradigm. The main purpose of the study was to use this paradigm in order to investigate whether sensation seeking is related to more intense phasic arousal reactions (arousability) or to more pronounced phasic activation responses (activatability) or to both. At first sight the results indicate that only arousability is related to sensation seeking, especially boredom susceptibility. Other possible explanations of the results are also discussed.

INTRODUCTION

In two important review articles Marvin Zuckerman (1984, 1990) has summarized and discussed the findings on the psychobiological correlates of the trait of sensation seeking. Correlations of this trait with psychophysiological reactivity measures and with neurochemical measures of neurotransmitters, metabolic enzymes and metabolites involved in the midbrain- and brainstem systems which activate cortical processes are interesting in themselves but more so if they can elucidate the different modes in which mammals have learned to react in an adaptive way to the biological importance of sensory stimuli. If we read him well, Zuckerman recognizes three fundamental modes (reflexes) which we have inherited from our ancestors: orienting followed by habituation, the defensive reflex and the startle (alarm or interrupt) reflex. These reflexes for reasons still unknown, show some variability with respect to the intensity and frequency with which they are used in humans. The sensation seeking trait is supposed to capture especially the strength of the orienting response to relevant novel stimuli which allows better focused attention to these stimuli. We quote: "I suggest that individual differences in reactivity to intense and novel stimulation, that provide the basis for the sensation seeking trait, may be the end result of natural variation in evolved A and W mechanisms in humans" (Zuckerman, 1990, p. 314). 'A' means approach and 'W' withdrawal in Schneirla's terminology (Schneirla, 1959). 'Seeking' is the evolved version of approach. And of course, effective seeking of prey, food, shelter, mate and offspring needs an alert registration system of meaningful stimuli or in other words a high capacity of focused attention. However, we wonder whether the startle reflex which is vital for survival is not even more intrinsically related to sensation 'seeking'. The reason is that we suppose that most of the data with respect to the psychoneurophysiological underpinnings of sensation seeking suggest that arousal which more and more seems to be the effect of the noradrenergic activation system of the brain, is the variable which best differentiates high and low sensation seekers (HSS and LSS).

The conceptual framework which to us seems most suitable to understand this aspect of sensory motor coupling in the brain, and the individual variations therein, is that of Pribram and McGuinness (1975) and Tucker and Williamson (1984). Taking as a starting point the model of attention proposed by Pribram and McGuinness (1975), the authors Tucker and Williamson (1984) stressed the importance of the difference between noradrenergic and dopaminergic arousal of the cortex. On the basis of the then available neurological evidence, which has been confirmed and expanded since (Clark, Geffen, & Geffen, 1987a, b, 1989), they concluded that the two systems exert different attentional functions. The main function of the noradrenergic system seems to consist in facilitating orienting to novel stimuli and habituation to repeated stimulation (selective sensory attention). The dopamine system's main function, however, seems rather geared at the preparation and facilitation of the coupling of the right response to stimuli (focused attention) [see also Weiner (1990), for an extensive discussion of these systems and their role in latent inhibition]. The noradrenergic system is the neural substrate of what Pribram and McGuinness (1975) have called the 'arousal system' whereas the dopaminergic system coincides with their socalled 'activation system'. Tucker and Williamson (1984) also cite some evidence that the noradrenergic and dopaminergic systems are differentially linked to the functions of the right and left hemisphere. The arousal system is supposed to sustain the special sensory capacities of the right parietal hemisphere while the activation system would rather support the sensory-motor capacities of the left frontal hemisphere.

Whereas neuro-anatomical evidence for uneven distributions of noradrenergic and dopaminergic nerve endings in the cortex of animals is abundant, human evidence is scarce and does not directly support the lateralization hypothesis (Gaspar, Berger, Febvret, Vigny & Henry, 1989). However this does not imply that a functional connection between the two cortical arousal systems and the hemispheres is excluded. For instance, Kittler, Turkewitz and Goldberg (1989) observed an initial left visual field advantage in correctly recognizing laterally and tachistoscopically projected complex visual patterns (kanji) and a shift towards right visual field advantage when the figures became more familiar. This finding is compatible with the idea that the right hemisphere which is specialized in quick holistic recognition of visual objects (Bradshaw & Nettleton, 1981; Kimchi & Merhav, 1991), recruits the special capacities of the arousal system to enhance the stimulus/noise ratio of the perceptual system when the stimuli are novel. Liotti and Tucker (1992) found a slowing of reaction times in *Ss* with induced depressive mood only to left visual field tachistoscopic stimuli. It has been demonstrated that depressive mood is associated with enhanced relative right hemisphere arousal (Schaffer, Davidson & Saron, 1983; Henriques & Davidson, 1990; Martinot, Hardy, Feline, Huret, Mazoyer, Attar-Levy, Pappata & Syrota, 1990; Tomarken, Davidson & Henriques, 1990; Henriques & Davidson, in press). Green, Morris, Epstein, West and Engler, (1992) found a positive correlation between right vs left cortical arousal in the EEG and a right vs left visual field disadvantage as measured by differences in reaction times in a lexical decision task. Using the Stroop-paradigm, Hughdahl and Franzon (1987) observed initial heart-rate deceleration during the first trial block only to stimuli tachistoscopically presented to the right hemisphere. Heart-rate deceleration typically occurs in situations involving orienting behavior. The authors also mention the finding of an association between increased right hemisphere evoked potentials and heart-rate deceleration, by Walker and Sandman (1979). All this evidence suggests that there might be a special link between the functions of the right hemisphere and the arousal system which facilitates orienting to novel stimuli. An indication of a preferential association between the sensory-motor coupling function of the left hemisphere and the activation system is for instance the finding by Kidd and Powell (1993) that persons with a pronounced schizotypical personality tended towards relative left hemisphere overactivation, as measured by diminished left hemisphere task-related α-power reduction in the EEG-waves. It has been sufficiently established that schizophrenia is associated with dopaminergic overactivation (Andreasen, 1988; Weiner, 1990). Consequently one may assume that schizophrenia prone persons have this left hemisphere overactivation because of an overactivated dopaminergic activation system. More direct evidence of a link between the dopaminergic system and the left hemisphere is suggested by the results of the post-mortem analysis of brain tissues of schizophrenic patients by Reynolds (1983) who observed a specific increase of dopamine in the amygdala of the left hemisphere. It has also been demonstrated that latent inhibition (LI), a phenomenon which is controlled by dopaminergic activation via the nucleus accumbens (Weiner, 1990), is attenuated in psychotic prone individuals in which a more elevated activation of the left hemisphere can be assumed (Baruch, Hemsley & Gray, 1988; Lubow, Ingberg-Sachs, Zalstein-Orda & Gerwitz, 1992). The findings of Craft, Gourovitch, Dowton, Swanton and Bonforte (1992) are also relevant for this issue. They found that male *Ss* with developmental dopamine depletion (phenylketonuria) showed a right visual field impairment in disengaging attention from an invalid cue in a reaction time test. They interpreted this phenomenon as a disruption of left hemisphere function. Dopaminergic activation, in general, seems to support and facilitate the selection and organization of sensory-motor associations by means of enhancing the stimulus-noice ratio of learned behavioral output programs in the supplementary motor areas of the cortex (Cohen & Servan-Schreiber, 1993). Dopamine neurons fire prior to and during the execution of learned movements but hardly show any activity in association with spontaneous movements (Servan-Schreiber & Cohen, 1992).

We have done several experiments to test the validity of the paradigm about the association between the arousal system and the right hemisphere on the one hand, and between the activation system and the left hemisphere on the other hand. In the experiments two discrimination reaction time tasks are used, one which is rather compatible with the capacities of the right hemisphere (pressing microswitches when two successively appearing stimuli on a monitor screen are in a predetermined position) and thus likely to be controlled by that hemisphere, and one left hemisphere task (reacting when two letters successively appearing on the screen are not both vowels of consonants). In both tasks, in randomly chosen trials, an unexpected preparatory signal appears a moment before the reaction stimulus (between 300 and 100 msec.). According to the combined hypotheses of Pribram and McGuinness (1975) and Tucker and Williamson (1984) the person should be startled when the unexpected signal arouses the person in the right hemisphere task and consequently the reaction time should be longer. On the contrary when the person is activated in the left hemisphere task an accelerated reaction (as a sign of elevated focused attention and behavioral preparedness) should be observed. In three successive experiments this seems to be the case (De Brabander, 1988; De Brabander & Boone, 1989; De Brabander, Gerits & Boone, 1990). Also in the sample of this study the paradigm seems to be valid (see the Results section).

In his 1984 review of research about sensation seeking in 'The Behavioral and Brain Sciences' Zuckerman summarizes in Table 1 the biological correlates of sensation seeking and their behavioral correlates in humans and animals. Inspection of the list of bioamines and neuroregulators shows that only those related to the catecholamines dopamine (DA) and noradrenaline (NA) are significantly related to sensation seeking. HSS seem to have lower levels of platelet Mono-Amine-Oxidase (MAO, the enzyme which catabolizes NA), decreased activity of Dopamine-Beta-Hydroxylase (DBH, the enzyme which metabolizes dopamine to NA) and lower Cerebro-Spinal-Fluid (CSF) levels of NA. The physiological relationship of the MAO and DBH measures with central catecholamine activity are not clear. Yet there seems to be some correlation between the presence in plasma of the catecholamines and their metabolites and CSF levels (Zuckerman, 1984; Degrell and Nagy, 1990). Also it appears that peripheral stimulation of sympathetic nerves which possibly affects peripheral DBH-activity, at the same time affects DBH-activity in the central nervous system (De Potter, Chanh, De Smet & De Schaepdryver, 1976). If we may speculate that platelet MAO is correlated with the rate of central catecholamine metabolic activity and that plasma DBH-activity is partly related to central DA to NA conversion, the results summarized by Zuckerman might be an indication of the fact that in HSS, possibly because of reduced metabolization as well as a higher rate of recapture, NA and DA stores in the central catecholaminergic nerves may be relatively higher than in LSS which implies a greater transmission capacity and consequently also enhanced effectiveness in arousing and activating the individual. HSS also seem to be augmenters of cortical evoked potentials whereas LSS tend to be reducers (Zuckerman, 1990; Zuckerman, 1984; Lukas, 1987). Finally, sensation seeking also seems to be related to more pronounced psychophysiological orienting (electrodermal response, heart-rate deceleration) to relevant stimuli (Ball & Zuckerman, 1992; Zuckerman 1984), Taken together these results suggest that in terms of our paradigm we can expect that HSS will show more arousal (retardation of reaction time after the unexpected signal in the right hemisphere task) and more activation (acceleration of reaction time after the unexpected signal in the left hemisphere task), than LSS.

Our paradigm about the different effect of unexpected preparatory signals on reaction times in a right vs left hemisphere task, allows us to distinguish startle from focused attention responses if one can consider that the retardation of the reaction in the right hemisphere task is a startle response and that the acceleration in the left hemisphere task is the consequence of a phasic increase in focused attention or orienting response to the relevant stimulus. If sensation seeking reflects a biological predisposition towards greater reactivity of both the arousal and activation systems, we can expect the scores on the sensation seeking scale to correlate positively with reaction delays after an unexpected preparatory signal in the right hemisphere task and negatively with such delays in the left hemisphere task.

METHOD

Subjects and procedure

The experiment was incorporated in a three week 'skills training course' in game theory for graduate students of economics at the University of Limburg (The Netherlands). The course started with a plenary session in which 52 students, who subscribed to the skills training course, were asked to fill in a questionnaire to assess sensation seeking.

Concerning the purpose of the experiment, we only announced that it was designed to deepen our and their understanding of behavior in a game setting. The students were promised feedback on the major findings of the research project after completion of the course. We also guaranteed strict confidentiality of the information provided by the questionnaires.

The reaction time experiment took place in the third week of the course. At that time, 12 students already quitted the course, leaving a total of 40 observations (26 males, 14 females). It should be mentioned that students at the University of Limburg are allowed to quit a course at any moment. It is unlikely that those students gave up because of the experiment, as the quit ratio does not differ from those of other courses. The remaining *S*s were randomly assigned to groups of 5–7 persons. The groups were successively invited to a room containing eight personal computers (PCs) for the experimental session.

Each *S* had to perform two reaction time tasks on a PC: a visuospatial and a semantic task. Both tasks consist of 100 trials. On each trial a white letter is displayed first on the midpoint of the PC monitor screen. The letter stays there until the end of the trial. After a random interval between 5 and 1.5 secs a second white letter is projected under or above the first letter. In the visuospatial task the *S* is instructed to press the spacebar of the keyboard as quickly as possible only if the second letter is displayed below (and not above) the first letter. On the semantic task the *S* must react only if the second letter does not belong to the same category as the first. The categories are vowels and consonants. The second letter appears under or above the first according to a random scheme and is of the same semantic category as the first in 50 of the 100 trials. The maximum time allowed to react is 0.4 sec in the visuospatial task and 0.5 sec in the semantic task, as the latter task is somewhat more difficult than the former.

On a number of trials randomly chosen by the computer program according to a 50% rate, an exclamation mark, about 5 cm high and 2 cm wide, appears at 10° of visual angle left and right of the letter on the midpoint of the screen. These preparatory signals are displayed at random moments between the time of 0.3 sec after the display of the first letter and 0.1 sec before the display of the second letter. Display moments are generated according to a rectangular distribution. The display of these signals lasts 0.18 sec.

After each trial in both types of tasks the following feedback was provided to the *S*s. If the *S* did not react when a reaction was required, 'too late' is displayed on the screen. 'Correct' appears on the screen after timely, correct reactions and 'error' after timely, incorrect reactions.

At the onset of the first group session, one of the authors randomly determined which task the *S*s had to play first. From then onwards, the task order was alternated in each of the other six groups. When a group arrived at the experimental room, a PC was assigned to each of the *S*s. Next, the experimenter gave instructions concerning when and how to react in the first type of task using a computer demo of the reaction game. The experimenter activated the computer program and the *S*s performed the first task simultaneously. After completion of the first task, the same procedure was used for the second task.

We motivated the *S*s by means of a promise that the top three performers in both of the tasks would receive a token for music records. Performance feedback was also used in order to stimulate quick and correct responses. Actually the amount of erroneous responses was very low, 6% on average. Performance was evaluated by calculating the ratio of the number of correct reactions divided by the average latency of these reactions. This ratio stimulates both correct and speedy reactions. We also appealed to the social motivation for prestige by telling the *S*s that the performance ranking would be announced in public in a final plenary session at the end of the course.

Measures

The so-called 'Spanningsbehoeftelijst (SBL)' developed by Feij and van Zuilen (1984) was used to assess sensation seeking. The SBL is a Dutch adaptation of the American Sensation Seeking Scale, more specifically the SSS-form V (Zuckerman, 1984). The SBL consists of 67 items, 51 of which are designed to measure sensation seeking (SS) (the other items are filler items). The respondents are asked to indicate on a five point scale to what extent they agree with each of 51 statements (1 = strongly disagree, 2 = moderately disagree, 3 = don't know, 4 = moderately agree, 5 = strongly agree). The scores of 15 items are reversed, so that a high score corresponds with high sensation seeking.

Ongoing research suggests that sensation seeking is partly a multi-dimensional personality construct operationalized by sub-scales with, possibly, different genotypic foundations (Zuckerman, 1979a, b, c; Feij and van Zuilen, 1984; Feij, Orlebeke, Ganzendam & van Zuilen, 1985). The following dimensions can be distinguished (Zuckerman, 1979a, b, c; Feij & van Zuilen, 1984):

(1) Thrill and Adventure Seeking (TAS): a desire to engage in physical activities involving some physical danger or risk.
(2) Experience Seeking (ES): the desire to seek novel experiences through travel, music, art, and nonconforming life-style.
(3) Disinhibition (DIS): the need to seek release in uninhibited social activities with or without the aid of alcohol.
(4) Boredom Susceptibility (BS): an aversion for repetitive experiences of any kind, routine work, or predictable people.

The SBL is designed to assess both these four sub-dimensions of sensation seeking as well as a total sensation seeking score.The number of items to assess TAS, ES, BS and DIS are 12, 14, 13 and 12, respectively. Scores for these sub-dimensions are obtained by summing the responses to the individual items. Thus the maximum scores for TAS, ES, BS and DIS are 60, 70, 65 and 60, respectively. The total sensation seeking score is the sum of the averages of the four sub-dimensions (minimum 4, maximum 20) (see Feij and van Zuilen, 1984). The following statements are examples of some SBL-items: "I would like to learn to fly" (TAS-item), "I like to wander around in a strange city on my own, even if it means getting lost" (ES-item), "I usually don't enjoy a movie or play when I can predict what will happen in advance" (BS-item) and "I like wild, uninhibited parties" (DIS-item). Extensive research among young adults suggests that the SBL is a reliable and valid measurement instrument (Feij & van Zuilen, 1984). The Cronbach α coefficients in the present study are 0.64 for TAS ($n = 40$, number of items 12), 0.71 for ES ($n = 39$, number of items 14), 0.67 for BS ($n = 40$, number of items 13), 0.69 for DIS ($n = 40$, number of items 12) and 0.78 for total sensation seeking SS ($n = 39$, number of items 51). These values are somewhat lower than those reported by Feij and van Zuilen (1984), but well above the lower limits of acceptability, generally considered to be around 0.50–0.60 (Nunnally, 1978).

The dependent variables are the following:

- Two measures of *arousal by the preparatory signals in the visuospatial task (right hemisphere task)*:

ARf = the average reaction time in correct trials wherein a preparatory signal is displayed minus the average reaction time in trials without preparatory signal, divided by the average of these average reaction times, multiplied by 100. The reaction times included in the calculations are all correct trials (late reactions included) wherein the *S* is required to react. ARf is calculated on the basis of the first 50 trials.

ARl = is similar to ARf but based on the last 50 trials.

The distinction between ARf and ARl is made in order to check whether the *S*s show habituation to the preparatory signals. If the delayed reactions after a preparatory signal are really the effect of a phasic response by the noradrenergic arousal system causing a startle reaction, then we should be able to observe a smaller effect in the last 50 trials. This expectation is based on neurological evidence [cited in Pribram & McGuinness (1975)] showing that noradrenergic nerves ascending from the locus ceoruleus decrease firing rates in response to repeated stimulation. Furthermore, there is more than abundant evidence (too much to cite) since Sokolov's early experiments that psychophysiological orienting responses controlled by the sympathetic nervous system decrease with stimulus repetition.

- Two measures of *activation by the preparatory signals in the semantic task (left hemisphere task)*:

ACf is analogous to ARf with this difference that the average reaction times in the formula concern the first 50 trials in the semantic task. The lower ACf the greater the degree of putative dopaminergic activation.

ACl is similar to ACf but based on the last 50 trials.

Since dopaminergic activation does not imply habituation to stimuli, on the contrary dopaminergic nerves seem to increase firing rates after repeated stimulation [evidence cited in Pribram & McGuinness (1975)] we also expect ACl to be lower than ACf or in other words we expect the phasic activation by the preparatory stimuli to increase with repeated exposure.

Figure 1 depicts the conceptual model and how the hypotheses fit in.

Analysis of data

Kolmogorov–Smirnov tests for goodness of fit indicated that all the variables used in the analyses can be considered as derived from a normal distribution. Consequently parametric statistical tests are used. The analysis consists of tests of the following working hypotheses which follow from our theoretical discussions in the introductory section.

Hypothesis 1. ARf and ARl are positively correlated with SS.

Hypothesis 2. ACf and ACl are negatively correlated with SS. Zuckerman (1979a, b, c, 1984) suggested that indices of noradrenergic and dopaminergic activity might be related differently to different subscales of the sensation seeking scale. If this suggestion is true and inferring from current knowledge of the psychological effects of the activation or inhibition of the NA and DA systems by various drugs one is inclined to expect that phasic arousal probably will be related more strongly to the boredom susceptibility and the disinhibition subscales while phasic activation could be related more strongly to the thrill and adventure and experience seeking subscales. However, we prefer to consider these expectations as exploratory.

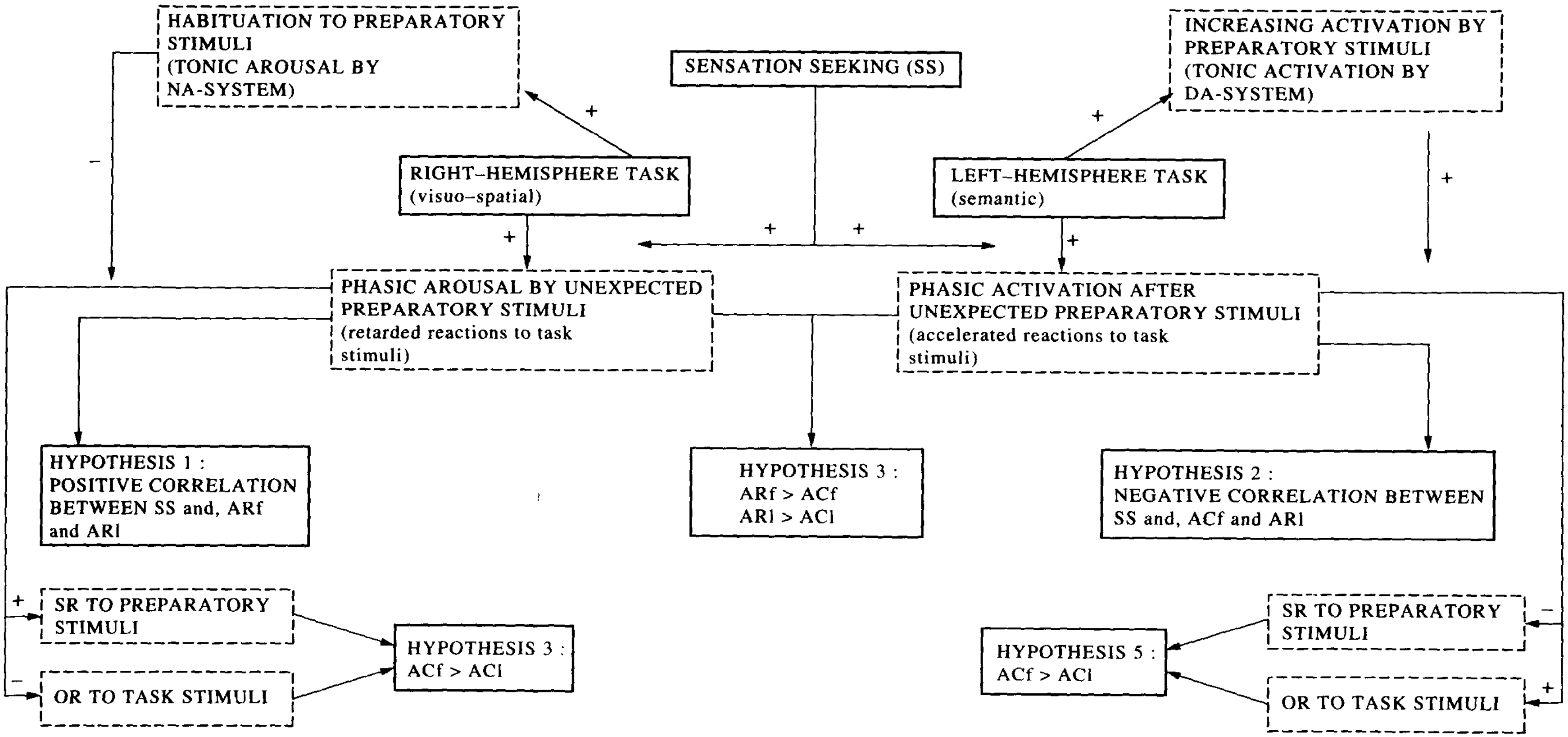
Hypothesis 3. ARf is higher than ACf and ARl is higher than ACl.

Hypothesis 4. ARl is lower than ARf.

Hypothesis 5. ACl is lower than ACf.

Hypothesis 3 is directly, and 4 and 5 are indirectly inferred from our basic paradigm. Remember that the higher ARf and ARl the higher the phasic arousal by the preparatory signal in the visuospatial (right hemisphere) task is supposed to be, and that the lower ACf and ACl the higher the phasic activation by the preparatory signal in the semantic (left hemisphere) task is assumed to be. Our first formulation of the paradigm was the following:

> "....If, just before a stimulus appears, a short preparatory stimulus is displayed the brain suddenly receives a supplementary information-processing load. If we assume that the same hemisphere which primarily attends to the task (by which we mean that it is responsible for encoding the response stimulus) also encodes the preparatory signal, then we can also assume that the effect of this preparatory signal upon task performance reflects the effect of a sudden increase in activity of the hemisphere performing the task. This is assumed to result in either increased activation when the left hemisphere controls task performance or in increased arousal when the right hemisphere is in control. But how can increases in arousal versus activation be detected? From their analysis of neurobehavioral data Pribram and McGuinness (1975) conclude that the arousal system acts on stop-mechanisms of behavior while the activation system acts on go-mechanisms, i.e. it truly activates. If this were the case in human subjects, activation should facilitate responses and arousal should inhibit." (De Brabander, 1988, pp. 783–784).



Notes : [solid box] hypotheses and experimental variables ; [dashed box] intermediate concepts

NA = Nor Adrenergic, DA = Dopaminergic ; SR = startle response ; OR = orienting response ; RT = Reaction Time

ARf = retardation of RT after preparatory stimuli in first 50 trials ; ARl = retardation of RT after preparatory stimuli in last 50 trials.

ACf = retardation of RT after preparatory stimuli in first 50 trials ; ACl = retardation of RT after preparatory stimuli in last 50 trials.

Fig 1. Conceptual model.

Table 1. Correlations between scores on sensation seeking subscales and total scale (SS) and dependent variables (see text)

	ARf	ARl	ACf	ACl
TAS	0.0002	0.2861	−0.0116	−0.0248
	(38)	(38)	(38)	(37)
	$P = 0.499$	$P = 0.041$	$P = 0.472$	$P = 0.442$
ES	0.1671	0.1404	−0.1156	0.1368
	(37)	(37)	(37)	(36)
	$P = 0.161$	$P = 0.204$	$P = 0.248$	$P = 0.213$
BS	0.5205	0.3901	0.0500	0.3480
	(38)	(38)	(38)	(37)
	$P = 0.000$	$P = 0.008$	$P = 0.383$	$P = 0.017$
DIS	0.2695	0.2937	−0.0748	0.1660
	(38)	(38)	(38)	(37)
	$P = 0.051$	$P = 0.037$	$P = 0.328$	$P = 0.163$
SS	0.4041	0.4668	−0.0364	0.2502
	(37)	(37)	(37)	(36)
	$P = 0.007$	$P = 0.002$	$P = 0.415$	$P = 0.071$

Notes: Number of cases between parentheses vary because of pairwise missing data.

P stands for chance probability.

ACf, activation scores in first 50 trials; ACl, activation scores in last 50 trials; ARf, arousal scores in first 50 trials; ARl, arousal scores in last 50 trials.

The more negative the activation scores the larger the degree of activation.

Facilitation of a response shows in a shorter reaction time and inhibition results in a delayed reaction time.

RESULTS

Table 1 depicts the correlations between the dependent variables and the scores on the subscales and the total score on the sensation seeking questionnaire. The number of cases on which the correlations are based is less than 40 or differ because of pairwise missing data.

From the bottom row it is apparent that only Hypothesis 1 is plausible and that Hypothesis 2 must be rejected. This seems to imply that sensation seeking is only related to arousability of the noradrenergic arousal system. If we look at the results of the correlations of the dependent variables with the scores on the subscales, TAS and ES, except for one scarcely statistically significant coefficient, do not seem to show any relationship with either arousal or activation, or more specifically with the phasic reactions to unexpected stimuli of these systems. DIS, but most significantly BS (boredom susceptibility) is clearly related to the phasic arousal measures in the expected sense. The relationship is weaker with ARl than with ARf which is compatible with the idea that the more pronounced arousal reactions of boredom susceptible *S*s gradually wear off because of habituation. One correlation with the phasic activation measures reaches a serious degree of significance namely, the positive correlation between BS and ACl. This result is in contradiction with Hypothesis 2 which already had to be rejected. But why this unexpected finding? In effect, it seems to corroborate the conclusion that only the functioning of the arousal system is related to sensation seeking. The most simple explanation is that even when a subject is performing a left hemisphere task, arousal may gradually overwhelm activation, and that boredom susceptible persons are more amenable to this phenomenon. In common sense language one could describe this phenomenon as follows. Initially boredom susceptibles and persons who are less so, are equally activated by the irrelevant preparatory stimuli in the left hemisphere task. (Note that the correlation between BS and ACf equals 0.05.) However, after a while the natural tendency of the boredom susceptibles to seek stimulation overcomes the tendency to divert attention from the irrelevant preparatory stimuli and they become gradually more aroused by them.

Table 2 displays the results of paired *t*-tests (comparisons are intra subject) needed to test Hypotheses 3, 4 and 5. The number of cases amounts only to 39 because of the fact that for one *S* there were not enough observations in one experimental condition to calculate a value for the dependent variable.

Table 2. Paired samples one-sided *T*-tests between average scores on the dependent variables (see text)

Variable pair	*N*	Mean	SD	*t*	Probability
ACf	39	− 1.05	7.69	− 1.86	0.035
ARf	39	2.78	11.18		
ACl	39	− 2.57	8.25	− 0.64	0.260
ARl	39	− 1.32	11.15		
ARf	39	2.78	11.18	3.65	0.001
ARl	39	− 1.68	11.14		
ACf	39	− 0.74	7.66	1.55	0.065
ACl	39	− 2.57	8.25		

Notes: ACf, activation scores in first 50 trials; ACl, activation scores in last 50 trials; ARf, arousal scores in first 50 trials; ARl, arousal scores in last 50 trials.
The more negative the activation scores the larger the degree of activation.

One can see that ARf and ACf are statistically significantly different in the expected direction. Also the signs of the averages are in agreement with our paradigm. In the right hemisphere task an unexpected stimulus seems to inhibit the subsequent reaction while the contrary seems to be true in the left hemisphere task. The difference between ARl and ACl (based on the last 50 trials) is not significant anymore. This seems to be due to the combined effect of habituation of the arousal system and of the increased activation in the last 50 trials. The average arousal reactions decrease from 2.78 to − 1.68, a highly significant difference. The average arousal reactions in the last 50 trials, however, are not statistically significantly different from zero ($t = 0.94$). Activation on the contrary increases from − 0.74 (ACf) to − 2.57 (ACl) ($t = 1.94$, $P < 0.066$). Remember that the lower ACf and ACl the greater the activation is supposed to be. ACl, however is significantly different from zero ($t = 1.94$, $P < 0.05$, one sided). These data seem to imply that the *S*s, after becoming familiarized with the preparatory signals gradually become less aroused by them, and more activated. The decreased arousal, however seems to be stronger than the increased activation so that the difference between arousal (ARl) and activation (ACl) in the last 50 trials is not significant anymore. So, we can conclude that Hypothesis 3 is partially validated. Hypothesis 4 is clearly validated and Hypothesis 5 seems to be valid but the evidence is not very strong. The least one can say, however, is that all the data are compatible with the basic paradigm which states that unexpected preparatory signals in a right hemisphere task are responsible for phasic arousal reactions which gradually wear off and for gradually increasing phasic activation reactions in a left hemisphere task. The decreasing arousal and increasing activation are the consequence of the typical functional characteristics of the noradrenergic and dopaminergic central activation systems which respectively effect the arousal and activation of the brain.

DISCUSSION

Recently Ball and Zuckerman (1992) published an article in this journal about differences in selective attention in a dichotic listening task between high and low sensation seekers (HSS and LSS). HSS tended to perform better on the shadowing task. This difference became statistically significant when the shadowing task had to be performed simultaneously with a light-detection-reaction time task. They also refer to two earlier studies which seem to indicate that HSS are better than LSS at focused attention. In one study (Ball & Zuckerman, 1990) HSS seem to learn multidimensional concepts with correlated attributes and nonreversal shift faster, because they are supposed to be able to focus more on the relevant attributes. In a study by Martin (1986) HSS located figures in an embedded figures test more quickly than LSS. The task used in the two first mentioned studies was a semantic task and the one in the last study a visuospatial task. In the framework of our paradigm these findings seem to indicate that sensation seeking correlates with tonic activation as well as tonic arousal which would explain why high sensation seekers perform better on both types of tasks. In our data we do not find any indication of the fact that sensation seeking is related to tonic levels of arousal or activation. The correlations between the sensation seeking scores and the average reaction times in the first fifty and the last 50 trials with or without preparatory signal, in the semantic as well as in the visuospatial task, are all close to zero and not statistically significant. Davidson and Smith (1989) did not find a significant difference in performance on a digit span test between HSS and LSS, either. Smith, Davidson, Smith, Goldstein and Perlstein (1989) also did not find a difference in performance of HSS and LSS on an auditory vigilance task but there was a difference in recall which interacted with stimulus intensity. In that experiment skin conductance level (SCL) and skin conductance response (SCR) differed between HSS and LSS, especially with more intense stimuli. In the Davidson and Smith (1989) experiment significant differences between HSS and LSS were found with respect to SCL but not SCR. Ridgeway, Hare, Waters and Russel (1984) on the other hand could not differentiate HSS and LSS on the basis of skin conductance orienting responses. All these results are difficult to interpret because of differences in tasks and experimental conditions in the different experiments. It is even more puzzling that in the Ball and Zuckerman study the difference in performance between HSS and LSS became only statistically significant when also the right hemisphere (and consequently the arousal system) was activated by a concurrent light detection task.

However, in the present study we were more interested in the reactivity or phasic reactions of the two attentional systems. Our a priori expectation was that phasic arousal and activation reactions to unexpected preparatory signals in a right and left hemisphere task respectively would be more pronounced among high sensation seekers. In Zuckerman's terms this means that we expected sensation seeking to correlate with the intensity of both startle responses (in the right hemisphere task) and, phasic uplifts in focused attention (in the left hemisphere task). Yet, at first sight, the results suggest that only arousability (or startle intensity) is related to sensation seeking.

A question one might ask is whether the more pronounced reaction delays in the visuospatial task and in the last 50 trials of the semantic task after the preparatory signals, of HSS and especially boredom susceptibles, are really startle responses as a consequence of phasic arousal reactions. Startle responses are the effect of passive attention or capacity not devoted to the task. The spare capacity is biologically important in order to allow the organism to orient to novel stimuli which could have biological significance. Another explanation for the increased reaction delays in boredom susceptible persons is that the reactions to the task stimuli are delayed after the preparatory signals because they allocate more active attention (capacity in use) to the preparatory stimuli so that less is left for the reaction stimuli. We regret that after the experiment we did not ask the *S*s some questions about the preparatory stimuli in order to check whether boredom susceptibles were more aware of or spent more processing capacity to those signals. For instance, we could have asked to estimate the proportion of trials in which flashes appeared on the screen. The approximation of the estimate to the real proportion would be an indication of active attention attributed to the signals.

Of course, both explanations are not mutually exclusive, and not really in contradiction with the arousal versus activation paradigm. In as far as passive attention or orienting coincides with arousal and active or focused attention with activation, our results could imply, on the one hand, that HSS, especially high BS persons, are more phasically aroused by unexpected stimuli in the right hemisphere task because their tonic arousal is lower and that therefore they show more pronounced startle responses (or phasic arousal responses). On the other hand, when performing a left hemisphere task wherein mainly the activation system is stimulated, high boredom susceptible persons would gradually start focusing more on the preparatory stimuli than low boredom susceptibles and thus have less attention left for the reaction stimuli. This would explain why the correlation between ACf and BS is insignificant while the correlation between ACl and BS is positive and highly significant.

The above interpretation of the results fits well the underlying concept of sensation seeking, namely that HSS and especially boredom susceptibles seek stimulation. Combined with our paradigm, however, this statement needs qualification in the sense that depending on the task the stimulation is brought about by either the arousal system or the activation system or both. Part of the contradictory findings with regard to the higher focused attention capacity of sensation seekers could probably be explained by right vs left hemisphere task-induced arousability vs activatability and the difference between HSS and LSS to attend to the task stimuli. Let us take the puzzling findings of Ball and Zuckerman (1992) we mentioned earlier as an example. It appeared, namely, that HSS performed better than LSS on the shadowing task when it was combined with a light-detection-reaction time task. Our explanation of this fact would be that HSS became more tonically aroused by the right hemisphere light detection task than LSS so that in the shadowing task HSS were less startled by the irrelevant stimuli and consequently performed better.

Finally, although this was not the prime purpose of the study, our results reconfirm the plausibility of our paradigm which allows us to tap phasic arousal (startle) reactions in a right hemisphere task and phasic increases in focused attention in a left hemisphere task. The predicted retardation of reaction times after an unexpected preparatory stimulus in the right hemisphere task and the predicted acceleration in the left hemisphere task, and also the diminishing of the former and accentuation of the latter with repeated trials were clearly apparent in the results.

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