Bilateral electrodermal activity during performance of cognitive tasks of varying difficulty levels

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Skin resistance responses (SRRs) were recorded bilaterally from right-handed males engaged in putative hemisphere-specific tasks of differing difficulty levels. In Experiment 1, electrodermal activity (EDA) was recorded while subjects were engaged in detecting a key word or a key word together with other words of related meaning from a prose passage (easy and difficult "verbal" tasks, respectively) and while engaged in a circle-circle or an arc-circle visual matching task (easy and difficult "spatial" tasks, respectively). EDA was a function of task difficulty, with smaller responses when subjects performed the more difficult "verbal" and "spatial" cognitive tasks. There was no evidence of asymmetrical EDA under any task condition. In Experiment 2, EDA was again a function of task difficulty, with less activity when subjects read more difficult prose passages aloud, and was again bilaterally symmetrical under each task condition. These results support the proposal of inhibitory cortical regulation of electrodermal activity but question whether this regulation is mediated only by contralateral pathways.

Attention has been drawn recently to the possibility of lateralized control of electrodermal activity (EDA), that EDA on each body side may be regulated separately from the other. Insofar as EDA is under cortical control (Venables & Christie, 1973), asymmetrical cortical activation may result in asymmetrical EDA. LaCroix and Comper (1979) reported task-related asymmetries of EDA which they interpreted as consequences of differential hemispheric activation in the different task conditions. In right-handed subjects, skin conductance amplitude was smaller on the right hand during performance of verbal tasks that were assumed to engage the left hemisphere preferentially, while the reverse asymmetry was found during performance of spatial tasks that were assumed to engage the right hemisphere preferentially. They proposed that the observed asymmetries resulted from inhibitory control of EDA on each side from the contralateral hemisphere. In this way, activation of a hemisphere was seen as inhibiting EDA on the contralateral body side. While this may be the case, it is not the only possibility. The asymmetries in EDA observed by LaCroix and Comper (1979) could equally well have resulted from an excitatory hemispheric system that controlled EDA on the ipsilateral body side, or perhaps by a more complex control system that included both contralateral-inhibitory and ipsilateral-excitatory regulation. This latter possibility is perhaps made more likely by cortical ablation and stimulation work, which suggests

both excitatory and inhibitory EDA control mechanisms at the cortex (Darrow, 1937; Schwartz, 1937; Wang, 1958).

Some insight into the control mechanisms might be gained by recording EDA bilaterally under conditions of graded hemispheric activation. If hemispheric control of EDA is by means of contralateral inhibition, then increased hemispheric activation should result in progressively less EDA on the contralateral body side. If control is by means of ipsilateral excitation, then increased hemispheric activation should result in progressively larger EDA on the ipsilateral body side. Cognitive tasks of graded difficulty offer a means of producing graded levels of hemispheric activation: McKee, Humphrey and McAdam (1973) showed that left/right EEG alpha ratios decreased progressively with increasingly difficult linguistic tasks. This approach was used in Experiment 1 where bilateral skin conductance responses (SCRs) were measured while subjects engaged in a verbal or spatial task at one of two levels of difficulty.

EXPERIMENT 1

Method

Subjects. Fourteen male undergraduates volunteered to participate. They ranged in age from 18 to 28 years. All were right-handed, as assessed on the Edinburgh Handedness Inventory (Oldfield, 1971).

Apparatus. SR was recorded from Ag/AgCl electrodes attached to corn pads (after Lykken & Venables, 1971) to circumscribe a recording area of 1 cm² on the volar surface of the middle phalanges of the index and middle fingers. The electrodes were secured with light-weight surgical tape. An electrode paste similar to that recommended by Lykken and Venables (1971) was made by mixing 100 ml of normal saline with 50 g of a neutral (bentonate) base.

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Skin resistance was recorded and amplified by Grass Model 7P1 low-level dc preamplifiers (which passed a 10- μ A current through the electrodes) and Grass dc driver amplifiers, and written out on a Grass polygraph with a chart speed of 50 mm/min. Preamplifier sensitivity was set at .5 or 1 mV/cm, depending on each subject's reactivity. The recording channels used for the left and right hands were alternated for successive subjects to eliminate systematic bias which might result from a residual difference in sensitivity following calibration.

The verbal tasks were similar to those used by McKee et al. (1973). In the easy condition, the subjects were asked to report the number of times a key word occurred in a passage of prose. In the difficult condition, the subjects were asked the number of instances in which the key word or any other word of related meaning appeared in a passage. The prose passages were of low arousal and interest value to match the spatial tasks. The spatial tasks were similar to those used by Nebes (1971). The easy task was a circle-circle matching test where the subject was required to match a target circle to a circle of the same size from several circles of different diameter. The difficult spatial task was an arc-circle matching test in which the subject was required to match a target arc of 120 deg to a circle of the same radius from several circles of different diameter.

Procedure. After electrode attachment, each subject was seated comfortably, with each arm resting on a molded foam armrest on a table in front of him, and allowed to rest for 10 min to permit the recording surfaces to equilibrate and to dissipate any effects of prior exercise. Task requirements were explained and any questions answered. The subject's arms were positioned about 70 cm apart to allow room to place the test material for easy viewing. For the verbal tasks, a recording trial began when a subject was given the text and continued until he neared the end of the text. Additional trials were given to accumulate a 5-min recording period. For the spatial tasks, 10 trials were given. Each trial consisted of a 30-sec recording interval which began immediately following presentation of the test material. The subject was told to remain silent and to continue to scan the test material until asked for his response. Two or three practice trials were given in a 2-min period preceding each task type. The practice trials were given to reduce electrodermal effects due to orienting when the subjects began the experimental trials. A 5-min rest interval was allowed between the two task types, and a 2-min rest interval between the two difficulty levels of each task type. Each subject was tested under all task conditions. Order of completion of the verbal and spatial tasks was counterbalanced across subjects, and the order of the easy and difficult tasks within each task type was determined randomly for each subject. Room temperature was maintained at $22^{\circ} \pm 1^{\circ}\text{C}$.

Data Analysis. Skin resistance responses (SRRs) were scored in the manner recommended by Edelberg (1967) and converted to conductance units. All responses with a pen deflection of at least 1 mm were scored. The resultant SCR amplitudes were range-corrected separately for each hand for each subject by expressing each score as a proportion of the SCR amplitude recorded following deep inspiration (Lykken & Venables, 1971). The range-corrected scores were summed over the 5-min recording interval and averaged to give left-hand and right-hand means for each subject under each condition. An alpha level of .05 was used for all statistical analyses.

Results and Discussion

Figure 1 shows mean range-corrected SCR amplitude for each hand in the four treatment conditions. SCR amplitude was smaller during performance of the more difficult task [$F(1,13) = 32.91$, $p < .05$]. The decrease in amplitude with increase in difficulty level was similar for both tasks. There was not a significant asymmetry of left and right SCR amplitude in any task condition. The mean number of SCRs in

Figure 1. Mean range-corrected SCR amplitude for each hand at each difficulty level of the verbal and spatial tasks. The vertical bars enclose one standard error.

each condition is given in Table 1. Fewer SCRs occurred during performance of the more difficult tasks [$F(1,13) = 6.01$, $p < .05$], and, like SCR amplitude, there was no significant asymmetry in any condition.

Two points can be made from these results. First, the finding that reduced EDA was associated with the more difficult task contrasts with the ipsilateral-excitation model which predicts that EDA should be greater when a subject is engaged in a more difficult cognitive task. Given the assumption that the more difficult tasks activated the hemispheres more than did the simpler tasks, this finding suggests that there is central inhibitory control of EDA. Second, there is no evidence for lateral specificity of this inhibitory control: the measures of EDA showed similar declines in both hands with increase in difficulty of both the verbal and spatial tasks. Tonic skin conductance levels (SCLs) were taken as the lowest values in each recording interval for the 10 subjects for whom these values were available. There was only small variation in mean SCL and no significant main effects were found. The similarity of mean SCLs in the two difficulty conditions (2.98 and 3.01 μmhos for the easy and difficult conditions, respectively) suggests strongly that the decreased phasic EDA activity in the difficult task conditions noted above was not secondary to an increase in tonic EDA activity with difficulty.

This failure to repeat the findings of LaCroix and Comper (1979) may have resulted from failure of the tasks used here to activate the hemispheres differentially. This possibility cannot be discounted because the instruction to subjects to engage in one or another cognitive task is not a strong manipulation of lateralized hemispheric activation. However, the tasks

Table 1
Mean Number of SCRs Recorded From Each Hand During Performance of the
Easy and Difficult Levels of the Verbal and Spatial Tasks in Experiment 1

	Verbal Tasks				Spatial Tasks			
	Easy		Difficult		Easy		Difficult	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Left Hand	19.8	2.8	12.6	2.9	16.2	3.1	11.1	2.8
Right Hand	20.9	3.0	14.0	2.8	16.6	3.1	12.8	3.1

were selected on the basis of EEG work (McKee et al., 1973) and work with commissurotomy patients (Nebes, 1971) which has indicated that they are hemisphere-specific. Furthermore, while some empirical support for LaCroix and Comper's (1979) result has been reported (Smith, Ketterer, & Concannon, 1981), there has been a report of a failure to find the asymmetry (Gross & Stern, 1980; Ketterer & Smith, 1977) as well as a report of an asymmetry in the reverse direction (Myslobodsky & Rattok, 1975). It may be that cortical control of EDA is not contralateral but is exerted over bilateral pathways from each hemisphere. Experiment 2 was designed to investigate this possibility.

EXPERIMENT 2

Interpretation of the previous experiment as well as of other work was complicated by uncertainty as to whether the particular tasks used produced differential hemispheric activation. As a consequence, the results gave no clue to the pathways by which inhibitory control of EDA is mediated. In the present experiment, an oral reading task was used in an attempt to have a stronger manipulation of lateralized hemispheric activity. This task was chosen because speech production appears to be the most strongly lateralized brain function. While the right hemisphere may be capable of some linguistic activity (Sperry, 1982; Zaidel, 1978), it does not appear to be capable of producing a sequence of meaningful speech (Gazzaniga, 1970; Searleman, 1977; Sperry, 1982). This left-hemispheric specialization for speech production is evident in the disturbance of right-handed (but not left-handed) manual performance by concurrent verbalization (Botkin, Schmaltz, & Lamb, 1977; Kinsbourne & Cook, 1971). Hicks (1975) went on to show that the degree of interference with the right hand's performance was a function of the phonetic difficulty of the verbalized material: the more difficult the verbalization, the greater the interference. Performance of the left hand remained unaffected. More directly, readiness potentials over premotor cortex are lateralized to the left hemisphere prior to production of speech sounds (McAdam & Whitaker, 1971). These results indicate that overt verbalization is controlled by the left hemisphere and

suggest that more difficult verbalization uses more of the functional capacity of the left hemisphere. In the present experiment, bilateral EDA was recorded while subjects read aloud text material of three different levels of difficulty. If inhibitory control of EDA is by way of contralateral pathways, then EDA should be smaller on the right hand in all test conditions, with the difference between the two hands greatest in the most difficult condition.

Method

Subjects. Seven right-handed male subjects volunteered to participate. They ranged in age from 21 to 24 years. They had not participated in the previous experiment, and none had studied biology at university level. This latter point is mentioned because the most difficult verbal condition contained many technical biological terms; the difficulty of reading would have been reduced for subjects familiar with the terminology.

Apparatus. Recording equipment and procedures were identical with those of Experiment 1.

The tasks were to read aloud from a page of text of one of three difficulty levels for a 5-min period. A newspaper report (on an art gallery) was used for the least difficult condition, a *Scientific American* paper (on pulsars) was used for the intermediate level of difficulty, and a report from the *Journal of Theoretical Biol-*

Figure 2. Mean range-corrected SCR amplitude for each hand at each difficulty level of the oral reading task. The vertical bars enclose one standard error.

Table 2
Mean Number of SCRs Recorded From Each Hand During Performance of the Easy, Moderate, and Difficult Levels of the Speech Production Task in Experiment 2

	Easy		Moderate		Difficult	
	Mean	SE	Mean	SE	Mean	SE
Left Hand	15.0	1.6	11.6	1.4	10.4	1.8
Right Hand	16.0	1.6	14.9	1.6	11.4	1.8

ogy (on the binding site and mode of action for photosystem II herbicides) was used for the most difficult condition. The material was also selected for low arousal value to minimize orienting responses.

Procedure. Task requirements were explained to the subjects, and any questions were answered prior to recording. The reading material was placed in front of the subject in a position where the whole page could be read easily. Recordings were taken from each subject under each difficulty level. The order of performance of each difficulty level was randomized for each subject. SRRs were recorded during a 5-min reading-aloud period in each condition. A 3-min rest period separated each condition.

Results and Discussion

Figure 2 shows mean range-corrected SCR amplitude for each hand in the three difficulty conditions. The effect of task difficulty is evident with smaller SCR amplitudes recorded during the more difficult oral reading tasks [$F(2/12) = 23.29$, $p < .05$]. Newman-Keuls tests showed that SCR amplitudes were significantly smaller in the intermediate and most difficult conditions than in the least difficult condition. The two former conditions did not differ. SCR amplitude was similar in both hands in all conditions; neither the main effect of hands nor the hands $\times$ conditions interaction approached significance. The number of phasic SCRs declined with difficulty level (Table 2), but the main effect of task difficulty was not significant. Newman-Keuls tests, however, showed significantly fewer responses in the easy task conditions than in the difficult ones for each hand.

These results replicate the earlier finding that EDA is a function of task difficulty, with less activity during performance of a difficult task than during a related easier condition. This gives further support for the inhibitory nature of EDA regulation during sustained mental work. The failure to find asymmetrical EDA during speech production suggests that the inhibitory cortical control of EDA is exerted bilaterally. It is, of course, impossible to make this inference strongly. However, given the evidence cited above that speech production is lateralized to the left hemisphere in normal right-handed males and given that the nature of the task (reading aloud) allowed verification that the subjects were engaged in the task continuously during the recording period, this negative finding does have some importance. Furthermore, the replication of the difficulty effect shows that the dependent variable was sensitive to a task variable. The failure to find an asymmetry at least requires that more compelling behavioral and elec-

trodermal evidence be presented to support the claim that central regulation of EDA is lateralized.

The consistent finding of reduced EDA during performance of the more difficult tasks was unexpected because nonspecific EDA amplitude appears to be determined in part by arousal level, with greater EDA associated with higher arousal levels (Raskin, 1973). The present finding might have emerged because the excitatory effect of novelty on EDA was reduced by familiarizing the subjects with the task to be done immediately prior to each recording run. Smaller EDA during performance of the more difficult tasks may then have resulted from more absorbed concentration on these tasks, a possibility suggested by Edelberg (1972).

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