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FACIAL ELECTROMYOGRAPHIC MEASURES DISTINGUISH COVERT COPING FROM STRESS RESPONSE TO STIMULUS THREAT

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Summary—Electromyographic (EMG) activity of the lip and chin muscles (obcularis oris, and digastricus) was monitored as subjects engaged in information processing underlying selection of stimulus alternatives associated with minimal likelihoods of aversive loud noise ("decisional control"). Based on previous quantitative analyses of the structure of decisional control, as the number of options increased, so did *both* potential threat reduction, and information processing demands. The above EMG activity corresponded to the availability of presenting options, and associated processing requirements. Cognitive work involved in assessing the available options was found to be stressing in its own right, as indicated by subjective reports and measures of sympathetic activation. The pattern of lip and chin EMG activity was opposite to that of medial frontalis (mid forehead) EMG activity, which tracked the relative threat of aversive loud noise. Results were discussed with respect to empirical correlates of the dimensions couched in formal models of decisional control, the measurement of coping in laboratory and other settings using EMG activity of selected sites, and the implementation of lip and chin EMG activity in operationalizing the concepts of "cognitive work done", and "cognitive efficiency".

There has been a considerable history of interest in the relation between facial muscle activity and emotion (Izard, 1971). To illustrate, Zajonc (1985) has recently revived hypotheses originally put forth by Israel Waynbaum on the possible role of facial expression in regulating emotion; Waynbaum's intriguing hypotheses date back to 1906 (see Waynbaum, cited in Zajonc, 1985). More recently, an upsurge in interest in relations between emotion and facial expressions has been seen; the increased interest has been prompted in part by Ekman and Friesen's (1978) provision of a method for systematically scoring observable facial expressions. Cacioppo, Petty, Losch and Kim (1986), in turn, have extended the analysis of observable patterns of facial muscle activity to those obtained from polygraphic records of electromyographic (EMG) activity. Both the valence and intensity of affective stimulus properties have been distinguished according to patterns of EMG activity over alternate facial muscle regions. Others have taken such analyses further, to the study of differential patterns of EMG activation assoiated with certain forms of psychopathology (Voglmaier, Bruder, Hakerem & Tenke, 1991).

Within the domain of negative affect, Prkachin, Currie and Craig (1983) have shown that even untrained observers are relatively sensitive to variation in aversive experiences of others, as revealed in facial expressions. Patrick, Craig and Prkachin (1986) have quantified changes in pain experiences employing the above Ekman–Friesen coding system. Also within the domain of negative affect, polygraphically monitored EMG activity has been employed extensively in research on stress and anxiety, indexing certain features of stress arousal, and individual differences in stress proneness (e.g. Balshan, 1962; Martin & Sroufe, 1970; Neufeld & Davison, 1974a). In this paper, we examine facial EMG responses to a selection of stressing situations that afford varying "opportunities for coping".

A region of the facial musculature yielding increased EMG activity with the occurrence of negative affect is the medial frontalis region (mid forehead). Cacioppo *et al.* (1986) observed that this area, along with that of the corrugator supercillia (brow), was more responsive to unpleasant auditory stimulation, and to visual stimuli of negative affective content (their plot study, and a *posteriori* comparisons of their main study). In contrast, other regions either did not distinguish

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affective states, or were responsive to pleasant sounds, and positive affective stimulus content. Because stress has been identified with negative affect (Lazarus, 1975), it might be expected that medial frontalis EMG activity would increase with stressing stimulation, including the "physical stress" of pain. Accordingly, rises in medial frontalis EMG activity have accompanied stimulation of bone pain (Davidson & Neufeld, 1974); presentation of visual stimuli (Neufeld & Davidson, 1974a; Neufeld, 1978), having appreciable stress-eliciting scale values (Neufeld & Davidson, 1974b); and psychometrically assessed individual sensitivity to such stimuli (Balshan, 1962; Neufeld, 1976). Reductions in medial frontalis EMG activity, on the other hand, have occurred to stress eliciting visual stimuli when presented in a context of "stress buffering" manipulations (Neufeld, 1976). The medial frontalis area, then, may be a region of the facial musculature of choice for monitoring the relative presence of aversive stimulus properties or events.

When encountering stressing situations, however, individuals presumably engage in coping activity. The situation permitting, such activity is directed at least in part toward reducing the relative presence of aversive stimulus properties or events (Gal & Lazarus, 1975). Might other regions of the facial musculature, then, convey the relative presence of certain categories of coping activity?

To pursue this possibility, we turn our attention to some forms of coping that bear on the responsivity of other selected regions of the facial musculature. Some methods of coping are considered to require in good part information processing, or "cognitive work" (see, e.g. Fisher, 1986; and for relevant formal definitions, Townsend & Ashby, 1978). Decisional control, for example, has been considered to vary with the number of options available to an individual in a stressing situation (Averill, 1973); effectively appropriating decisional control requires the processing of information necessary to selecting option(s) harbouring minimal threat. Facial muscle regions that may be activated by such processing include those of the lip and chin. These areas have produced increased EMG activity, for instance, when *S*s have prepared counterargumentation against a presented personally-involving counterattitudinal argument (Cacioppo & Petty, 1979a); when they have engaged in tasks requiring the processing of phonetic and semantic features of verbal stimuli (Cacioppo & Petty, 1981a); and, when they have encoded verbal stimuli with varying degrees of elaboration, such as encoding semantic compatibility with "self schemata", versus encoding topological features comprising upper and lower case script (Cacioppo & Petty, 1979b; for a review, see Cacioppo & Petty, 1981b). Thus, lip and chin region EMG activity may indicate the degree to which "cognitive work" is being undertaken, including that cognitive work involved in coping activity.

Like aversive stimulus events, cognitive work can be stressing in and of itself (Fisher, 1986; Hamilton, 1980; Hockey, Gaillard & Coles, 1986; Schonpflug, 1986; Wright, 1987); because the associated expenditure of energy presumably can be aversive (Neufeld, 1990a), negative affect is likely to occur (Lazarus, 1975). In these ways, then, lip and chin muscle activity may trace variation in cognitive work as an agent of stress in its own right.

If activity of lip and chin musculature is to successfully follow the path of covert coping in the form of information processing, it must be *sensitive*, in the psychometric sense of covarying with the measured variable, or construct. It must, however, also be psychometrically *specific*. The muscle regions monitored by Cacioppo *et al.* (1986) illustrate these properties. Activity of one of their muscle regions (corrugator spercilia) increased as stimulus properties increased in negative affect content, but not as they increased in positive affect content; activity of two other regions (zygomotor major and obicularis oculi) was sensitive and specific to increases in positive affective content. Along these lines, if EMG activity in the lip (obicularis oris) and chin (digastricus) regions are not appreciably specific to "cognitive work", they may be of little value in differentiating the "stress of coping" from other sources of stress. Other "sources" include specifically stressing stimulus properties (e.g. social evaluation, or threat of physical discomfort), and psychometrically measured susceptibility to such properties (as described above, with reference to the medial frontalis region). The required differentiation will be absent (a) if a generalized increase in EMG activity across all regions of the facial musculature attends an increase in stress, regardless of the latter's source, or (b) if some subset of regions generally are stress responsive, while others simply are not.

The above dissociation of sensitivity becomes all the more important when alternate sources of activation tend to be mutually exclusive. This requirement again can be illustrated with respect to

Cacioppo *et al.*'s (1986) study of the differentiation of affect. For their experimental stimuli, relative presence of positive affective stimulus properties signified the relative absence of negative affective properties, and the opposite. Given this type of inverse relation with respect to the affective valence of stimuli, facial EMG activity would be of little diagnostic value regarding which valence of affect were present, without the measurement specificity referred to above.

In a similar vein, to affective valance of stimulus properties, the cognitive work associated with decisional control, and threat of aversive stimulus events, tend to be mutually exclusive, according to formal "game theoretic models" of decisional control (Morrison, Neufeld & Lefebvre, 1988; Neufeld, 1990b). Situations relatively rich in opportunities for decisional control plainly afford its benefits, in the way of threat reduction, but in so doing, intrinsically exact an associated "cost" of heightened cognitive work; conversely, situations lacking in opportunities for threat reduction inherently entail commensurately less cognitive load.

In the present study, lip and chin EMG activity were monitored while *S*s to varying degrees processed information upon which threat reduction was contingent. Situations simulating differing opportunities/constraints on decisional control experimentally were administered, according to a previously established paradigm (Morrison *et al.*, 1988). The latter investigators found that medial frontalis EMG activity significantly increased with increasing threat of aversive stimulation (loud noise). The paradigm under which measures were obtained, identical to the present paradigm, and employing a sample from an identical population, afforded a medial frontalis profile against which the current measures of lip and chin activity could be superimposed.

A "strong test" of the specificity of lip/chin EMG activity was undertaken in the following way. Recall that both threat of aversive stimulus events, as well as cognitive work, as agents of stress are considered to fall within the domain of negative affect (Lazarus, 1975). Hence, lip and chin EMG activity is required to track one *dimension* of negative affective stimulation over and above another dimension. This requirement contrasts that where muscle regions are required to covary with negative affective stimulation over and against affective stimulation of the opposite valence (Cacioppo *et al.*, 1986). On the other hand, specificity to the above dimensions of stress may be expected to occur, to the extent that information processing that is part and parcel of decisional control activates only selected regions of the facial musculature.

METHOD

Subjects

*S*s were 42 healthy male undergraduates between 17 and 25 years of age, from the University of Western Ontario. They were given course credit for participation. A single sex was used in an effort to reduce error variance due to sex differences in responsivity on dependent variables (Cacioppo *et al.*, 1986; Neufeld & Davidson, 1974a). A female experimenter served throughout.

Overview

*S*s participated in 2 experimental sessions, separated by a 15-min break. The first session was designed to "acquaint" them with experimental stimuli, to be employed in the second session. Stimuli, alphabetic letters, were variously endowed with stressor properties, according to an earlier established paradigm (Mothersill & Neufeld, 1985; Neufeld & Herzog, 1983; Morrison *et al.*, 1988). The letters acquired histories of stressor and innocuous associations according to a probability learning methodology based on associational memory models (Estes, 1975, 1976, 1977). During the second session, arrays of the stimuli comprised "stressor situations" to be negotiated through decisional control. Procedures again were based on an earlier established paradigm; a game-theoretic framework (see, e.g. Rappaport, 1983) was employed experimentally to implement decisional control, and its stress-related costs and benefits (Morrison *et al.*, 1988; Neufeld, 1982, 1990b). Participation consumed from 3 to $3\frac{1}{2}$ hr, and took place at one time so as to eliminate truancy during the second session.

Session 1

Procedure

*S*s were presented with two rounds of "learning trials", each round being followed by a round of "probability judgment trials". Each round of learning trials consisted of 104 presentations of alphabetic letters combined with stressor or "innocuous events". Ten alphabetic letters were chosen such that the probability of misidentifying one for another was <0.10, according to Townsend's (1971) confusion matrix. Letters were presented on a Sanyo Model 194 videomonitor.

Each stressor event was a 1-sec presentation of 104 or 108 dB (randomly determined) white noise (S.P.L. at the ear), delivered through Maico headphones; each benign event was a 1-sec illumination of a green light, atop the video monitor. The present type of noise stimulation has served in this and other settings (see, e.g. Fisher, 1986; Glass, 1977), and its stressing properties have been documented according to Thurstonian scaling of its subjective and psychophysiological effects (Neufeld & Herzog, 1983; Lefave & Neufeld, 1980).

The probability learning paradigm was based on procedures used by Mothersill and Neufeld (1985) and by Neufeld and Herzog (1983), and was identical to that of Morrison *et al.* (1988). During each trial, a letter appeared on the video monitor for 2 sec. Three seconds later, the 1-sec stressor or benign outcome occurred. A 4-sec inter-trial interval separated the end of the outcome interval and the subsequent letter presentation.

The letter–outcome combinations forming the 104 presentations comprising the round of learning trials are given in Table 1. Also included are the conditional probabilities of noise, given the letter appearances. For example, the letter B appeared 12 times, and was followed by the noise 4 times, and the light 8 times, for a conditional probability of noise of 4/12 = 0.33. Four sequences of randomly-ordered letter–outcome combinations were prepared, and were arranged into 2 pairs of sequences. One sequence of the pair formed the first round of learning trials, and the second formed the second round. Each *S* independently was assigned to one or the other pair. *S*s were informed of the protocol of learning and judgment trails, and were asked to try to rememeber "... the extent to which each letter was followed by a noise or light outcome." In addition, *S*s pronounced the letter, and name of the outcome, "noise", or "light", to facilitate encoding of the letter–outcome combinations (Estes, 1976).

One minute following each round of learning trials, *S*s judged the probabilities of noise occurring to the respective letters. Each letter appeared on the monitor for 2 sec, followed by the judgment during the next 6 sec. Judgments were registered by placing a slash on a line demarcated by 0, 25, 50, 75 and 100%. Letters were randomly ordered independently for each round of judgment trials. The pair of learning and judgment trial rounds were separated by a 2-min rest interval.

In general, judgments within this paradigm tend to parallel the relative frequencies of noise, and to a lesser extent the conditional probabilities of noise, given letter occurrence (Morrison *et al.*, 1988; Mothersill & Neufeld, 1985; Neufeld & Herzog, 1983). Note that relative frequencies of noise and light essentially are uncorrelated in the present instance, $r = 0.02$, an association made possible by the unequal frequencies of letter appearance (cf. Estes, 1976). The obtained pattern of judgmental influences occurs for reasons conveyed by Estes' formal model of "categorical memory" (Estes, 1976; see also Einhorn & Hogarth, 1978). For the present purposes, use of this paradigm ensures that associational-memory mechanisms of probability learning are in effect, making for differential anticipatory stress to the various letters. Accordingly, means of the above judgments correlate 0.89 with the relative frequency of noise, 0.78 with the conditional probability of noise,

Table 1. Probabilities and frequencies of stimulus presentation

Letter Stimulus	D	B	J	L	M	A	Z	V	P	G
Letter frequency	7	12	9	5	9	6	14	11	18	13
Relative frequency of noise	5	4	1	2	2	4	6	7	8	9
Relative frequency of light	2	8	8	3	7	2	8	4	10	4
Conditional probability of noise, given letter occurrence	0.71	0.33	0.11	0.40	0.22	0.67	0.42	0.64	0.44	0.69

and −0.23 with the relative frequency of light (Morrison, 1985). Mean reported subjective stress correlates 0.99 with the relative frequency of noise, and 0.76 with the conditional probability of noise (Neufeld & Herzog, 1983).

Session 2

Design, and decisional control paradigm

The experimental layout comprised a randomized blocks factorial design. Factors included *S*s as blocks ($n = 42$), and, as within-blocks factors, relative availability of decisional control (6 levels), number of potential alternatives within conditions of decisional control (2 levels), and number of presentations of the 12 decisional control alternative-size combinations, or "trials" (2 levels). The number of potential alternatives displayed during each trial was either 4 or 8 letters, randomly selected from the original 10. The conditions of decisional control were implemented according to earlier procedures of Morrison *et al.* (1988). For each trial, the 4 or 8 letters were divided evenly into two sets, set sizes, labelled q, thus being 2 or 4 ($q = 2,4$). During each trial, the simulated situation represented by the letter array was "engaged" by choosing one of its accessible alternatives. The likelihood of subsequent loud noise (a stimulus identical to that used during the first session) was proportional to the relative frequency with which noise occurred to the encountered alternative during the first session. Accessibility of potential alternatives simulated the availability of decisional control, as defined above.

In the first condition, both letter sets were accessible as were the letters within each set, a "choice-choice" position (*Cc*). In the second condition, choice of the letter set was accessible, but the specific letter to "determine" noise probability randomly was designated from the selected set. That is, choice over the set was accessible, but the letter to be effected within the set was uncertain (*Cunc*). In the third condition, either set could be chosen, but choice of the specific letter within the set was unavailable; however, the specific letter to be encountered within each set was made apparent at the outset of the display (*Cno*). The remaining three conditions resembled the first three, with respect to choice governing letters within sets. However, only one of the two sets was accessible in each case, the specific set randomly being pre-assigned (*NOc*, *NOunc*, and *NOno*). Noise delivery for conditions *Cunc* and *NOunc* was based on relative noise frequency during Session 1 of a letter randomly selected from the chosen (*Cunc*) or assigned (*NOunc*) set.

The six conditions varied with respect to three properties pertinent to decisional control. The first property was the availability of decisional control itself, defined as the number of letters, or sets of letters (*Cunc*, *NOunc*) available to the *S* for selection during that given trial—Response Set Size (RSS); the second was the number of letters that needed to be considered to identify the candidate, or set containing the candidate (*Cunc*), bearing the least subjective likelihood of noise occurrence—Outcome Set Size (OSS)—in the case of *NOunc* and *NOno*, *OSS* corresponded to the number of letters that needed to be considered to appraise the threat status embodied in the presenting array; and the third was the probability that the alternative having the least subjective likelihood of stressor occurrence among the 4 or 8 letters in the array at large would be the one "encountered", given appropriation of the available presenting control—Probability of accessibility of least-threat alternative [$Pr(t_l)$].

The latter property represents the relative potential threat reduction in the multi-alternative situation afforded by the presenting condition of decisional control. Assuming random designation of (un)available letters, and given implementation of available control, $Pr(t_l)$ has been shown across the above conditions of control to correlate highly negatively ($\leqslant -0.92$) both with the mean of stressor probability, and with the "variance in the outcome-events experienced" (stressor occurrence arbitrarily assigned a magnitude of 1.0, and its absence, 0, Neufeld, 1990b). Event variance is taken into account because unpredictability may be stressing in its own right (e.g. Paterson & Neufeld, 1987). Advantages of employing $Pr(t_l)$, including its comprehensiveness and generalizability across the present conditions of decisional control, over related indexes of potential theat reduction, quantitatively have been stated elsewhere (Morrison *et al.*, 1988; Neufeld, 1990b).

Table 2 lists the above three properties across the 6 conditions of control. OSS correlates with each of RSS and $Pr(t_l)$ by a value of 0.74 for $q = 2$ and 0.61 for $q = 4$; RSS and $Pr(t_l)$ correlate perfectly in each case (Morrison *et al.*, 1988). Overall, then, as opportunity for decisional control

Table 2. Response Set Size (RSS), Outcome Set Size (OSS), and probability of availability of least-threat alternative $[Pr(t_l)]$ over conditions of decisional control (q = 2,4)

Condition	*Cc*	*Cunc*	*Cno*	*NOc*	*NOunc*	*NOno*
RSS	$2q$	2	2	q	1	1
OSS	$2q$	$2q$	2	q	q	1
$Pr(t_l)$	1	$1/q$	$1/q$	1/2	$1/(2q)$	$1/(2q)$

increases, threat reduction, in the form of increased $Pr(t_l)$, can be affected, contingent on increased "cognitive effort". The cognitive activity roughly entails generating predictive judgments of stressor occurrence by encoding the relevant letters according to their memorial relative stressor frequencies.

Note that it is assumed that selection of the letter set in condition *Cunc* is based on the location of the letter having the least subjective stressor likelihood in the array at large (t_l). Other strategies of choice under uncertainty of course may be employed. These strategies have been considered in detail elsewhere (Morrison *et al.*, 1988); their possible operation does not lead to predictions in the present study departing materially from those emanating from the assumed choice strategy. Finally, with respect to condition *NOunc*, it is assumed that individuals generate predictive stressor judgments regarding potential letter occurrences, even if choice of the one to be encountered is unavailable (e.g. Neufeld, 1982); ambiguity concerning possible encounters is minimized, even if ambiguity concerning the specific encounter to take place remains unaltered.

Procedure

*S*s were given 12 practice trials with displays representing the combinations of 6 control conditions for each of q = 2 and 4. Letters were different from those used subsequently during the 24 test trials. Instructions were as follows:

> "You will again be presented with upper-case alphabetic letters, only this time, they will appear on the screen in sets of two or four letters. Your task is to choose the one letter that you think will have the least chance or probability of being followed by noise. You learned each letter's probability of noise outcome during the previous phase of the experiment. Although you may not know or remember which letters are associated with exactly what probabilities, do your best to judge which letter out of each set is least likely to be followed by noise.
>
> You may not always be able to choose the one letter that you want to select. Not all the letters presented will be available for you to choose from. In fact, you will only be able to choose an individual letter if it has a small "x" immediately above it. Also, you will only be able to choose an individual letter with an "x" above it if it is a member of a letter set which has a large "X" above it.
>
> In order to make your set and letter selections, simply say out loud which letter or set you feel is the correct choice—that is, the least likely to result in a noise outcome. The letters will be presented to you for 15 seconds. As soon as you see the letters on the screen, select your letter and state what it is out loud as quickly as possible. In cases where you can only choose a set, but not an individual letter, simply state out loud the set number (left or right) you have chosen.
>
> A few seconds after you have made your response, you will be presented with the outcome—either a noise or a light, which was associated with the letter you chose. Therefore, if you felt the letter T was least likely to be followed by noise, and you chose this letter or had it assigned to you, and if T was in fact not very highly associated with noise, you will probably see the light after you say T. However, if instead you said H, and if H was highly associated with noise, then you will probably hear a loud noise after you say H.
>
> Remember that your task is always to choose the letter or set least associated with noise. However, even if you choose the correct letter or are assigned the letter least associated with noise, it is still possible that sometimes you will get the noise after you say your response. Because we are dealing with probabilities, there is always a chance that noise will occur instead."

Because they involved novel letters, practice trials were accompanied by a handout presenting hypothetical arbitrary probabilities of noise, ranging from 0.05 to 0.98, to the respective letters in the display. *S*s were asked to make reference to these values when making their selections.

Letter arrays appearing on the video screen resembled the arrays to be used during the test trials. They were displayed horizontally and spatially separated into 2 sets. An upper-case "X" above a set indicated availability of the set, and a lower case "x" above a constituent letter indicated availability of the letter. In condition *Cunc* and *NOunc*, only upper-case "Xs" for the accessible letter sets were used; in conditions *NOc* and *NOno*, lower-case "xs" appeared in each set, but only one of the sets had an upper-case "X". Feedback regarding the "accuracy" of selection was provided according to whether or not the accessible letter having the least noise probability, or the letter set containing the letter having the least noise probability, was selected. In the case of *Cunc*, the least-probability letter invariably was located in the set with the least average probability, this also being the case for the 4 test trials involving this condition.

Procedures were designed to encourage as much as possible the implementation of available decisional control—selection of the least-probability letter or letter-set available. Interest lay in the activation of presenting decisional control and its correlates. It was quite possible that *S*s may have elected to forfeit control and its threat-reducing benefits, at least on some trials (Neufeld & Paterson, 1989). Their doing so unnecessarily would have complicated interpretation of results.

Following the practice trials, clarification of procedures was provided, if necessary. (*S*s were told that any selection of a designated inaccessible item would be followed by a request for a new selection, an unnecessary requirement, as all errors of this kind immediately were self-corrected.) Test trials then proceeded as follows. Each letter array appeared singly on the monitor for 5 sec, with its onset accompanied by a brief, 22 msec tone (500 Hz, 104 dB S.P.L. at the ear), designed to orient the *S* to the video presentation (Solley & Thetford, 1967). Each verbal selection response was followed by the experimenter's prompt ("rating"), upon which the *S* rated verbally according to a 5-point scale (1 = "no stress", 5 = "extreme stress") the amount of stress experienced during the preceding decision process.

If *S*s had not stated their selection within 15 sec of the display offset, a "Give response now" sign (accompanied by the signal tone described above) appeared on the video monitor for 2 sec. This requirement seldom came into play. Finally, 52 sec after the initial letter array offset, either the loud noise, or light outcome was presented. Inter-trial interval was 37 sec.

Measures

Measures were obtained during the experimental task of EMG activity, as well as of heart-rate and skin-conductance responses. The latter two measures were taken so as to monitor activation by the present paradigm of these two modalities, and to enrich the informational context within which to interpret the EMG measures (Morrison *et al.*, 1988).

To attenuate the possible influence of demand characteristics on muscle activity (Cacioppo, Petty & Marshall-Goodell, 1984), *S*s were told that multiple sensors were placed on different locations—face, hands and arms—to measure general involuntary physiological states. Attention to the speech musculature was reduced by telling *S*s that the facial sensors instead could have been placed on the upper portions of the face, but that hair and/or spectacles may have interfered with their placement for certain individuals. The even balance of electrodes between the face and elsewhere was designed to fortify the impression that the facial musculature was not the site of principal interest. Earlier medial frontalis muscle recordings from a study addressing different issues (Morrison *et al.*, 1988), but using a paradigm, recording techniques, and *S* population identical to those of the present study, allowed comparison to the current results; moreover, it afforded the present use of only 2 pairs of face electrodes. Thus, the avowed interest in general involuntary physiological states credibly could be put forth without proliferating facial and other electrode placements, the former possibly detracting from cognitive task performance. Overall, recording methods were patterned after procedures established in the present stress laboratory, and in others specializing in EMG recordings (e.g. Mothersill, Dobson & Neufeld, 1986; Cacioppo & Petty, 1979a, b).

Electromyographic responses

Lip and chin (obicularis oris, and digastricus) activity was monitored with a Grass Model 7 P3B preamplifier. Surface electrodes—Beckman 10 mm-dia, silver–silver chloride, used with Beckman EEG type EC 2 electrode cream—were placed approx. 1 mm below the apex of the lower lip at each corner of the mouth. For chin muscle activity, electrodes were placed on the midline of the chin, the first approx. 1.8 cm above, and the second 1.8 cm below the point of the chin. Scores for

EMG activity were obtained for the last 5 sec preceding the practice trials of experimental session 2 (baseline), and during the interval from the array onset to the verbal selection response of each of the 24 test trials.

Scores comprised average microvolts of recorded myoactivity over each sampled period, as follows. The pre-amplifier low-frequency time constant was set at 0.04. The integrator circuit time constant was placed at 0.2, permitting a satisfactory compromise between "signal stability" and responsiveness to change. Integrator circuit threshold was adjusted to place the zero signal at 0.6% of full scale deflection. The raw EMG signal thus continuously was integrated over a 0.2 sec interval. The integrated signal was monitored continuously, and its average value over the scoring interval was divided by that generated by the 200 μV calibration signal. This proportion was multiplied by 200 to yield the final value for the monitored interval. Emphasis, then, was on mean amplitude (Cacioppo *et al.*, 1986; Cacioppo, Petty & Morris, 1985)—the first raw moment of amplitude (Cacioppo, Marshall-Goodell & Dorfman, 1983). In idealized terms, each score formally can be represented as the following integral:

$$[\int_{t'=0}^{t'=t} f(t')\partial t']^{-1} f(t') \int_{t'=0}^{t'=t} \int_{x=0}^{x=\infty} f_{t'}(x)x\partial x\partial t',$$

where t' is the point of integrated-signal measurement between O and t, O representing the commencement of the scoring period and t being the size of the scoring interval (in seconds); $f_{t'}(x)$ is the empirical probability density of EMG amplitude x during the interval between $t' - 0.2$, and t'; and $f(t')$ is the probability density of sampling at time t' ($O \leqslant t' < t$), which is constant. Finally,

$$\int_{t'=0}^{t'=\infty} f(t')\partial t' = \int_{x=0}^{x=\infty} f_{t'}(x)\partial x = 1.00.$$

Heart-rate

Heart-rate measures were obtained using a Grass Model 7 P4F Tachograph pre-amplifier. An electrode (see above) was placed on each forearm (at the site with minimal hair), with a ground clip fastened to the left earlobe. Heart-rate acceleration (HR ACC) and deceleration (HR DEC), repsectively were scored as the fastest and slowest beats per minute (e.g. Mothersill *et al.*, 1986), during the same baseline and experimental task periods as those for EMG activity.

HR ACC has been associated with anticipated informational demands (Dobson & Neufeld, 1981; Endler & Magnusson, 1977), as well as covert information processing (Obrist, 1981); HR DEC has been indicative of visual intake of external stimulation (see, for example, Eves & Gruzelier, 1984; Lacey,1972). The varying visual and memory search demands across the conditions of control in the present paradigm differentially were expected to activate these components of cardiac response (Morrison *et al.*, 1988; Pribram & McGuinness, 1975).

Skin-conductance

Skin-conductance (SC), scored as [1/(resistance, in ohms) 10^6] was obtained using a Grass Model 7 P1E pre-amplifier. Electrodes (see above) were placed on the index and third fingers of the *S*'s non-preferred hand. Values were obtained for the above baseline and test intervals.

SC has been shown in experimental stress studies to be relatively sensitive to "attention-eliciting properties of the stimulus complex," including intensity, complexity, and novelty (e.g. Dobson & Neufeld, 1981; Geer & Klein, 1969; Lefave & Neufeld, 1980).

Subjective stress

Scores consisted of the ratings on the 5-point Likert-type scale, described above.

Response time

This measure comprised simply the time in *s* between the letter display and the verbal selection response.

Noise probability of selected/assigned items

These values were based on the *S*'s judged probabilities, averaged over the 2 judgment trials in the first session, for the selected or assigned letters of the trials in the second session.

RESULTS

Scores for EMG activity, HR ACC, HR DEC, and SC were analysed using the randomized blocks design described above. Analyses of covariance were employed, with baseline values serving as the covariate. Although no adjustment is made for within-*S* effects, results tend to throw into relief changes taking place across conditions, in effect setting a comon baseline for all *S*s (Cacioppo & Petty, 1979b). Huyhn-Feldt adjusted degrees of freedom were used to test the main and interactive effects of the within-*S*s conditions-of-decisional-control factor (CDC).

Multivariate analysis of covariance was considered otiose because the factor of principal interest, CDC, invariably produced highly significant effects when tested at the univariate level, below. Moreover, the multivariate extension of adjustment in univariate degrees of freedom for non-sphericity of variances and covariances across multiple levels of within-*S* factors, although established mathematically (Boik, 1988), has yet to be introduced into available computer packages. Consequently, a bonafide counterpart at the multivariate level of the univariate analyses was unavailable.

Lip EMG activity

The main effect of CDC was highly significant, $F(5,192) = 20.27$, $P < 0.001$. The left panel of Fig. 1 displays means across the conditions, each mean collapsed over trials and letter-set sizes ($q = 2,4,$). Paired comparisons among conditions (Neuman-Keuls *a-posteriori* procedures) indicated that EMG activity for each of *Cc*, *Cunc*, *Cno* and *NOc*, was significantly elevated relative to that of conditions *NOunc*, and *NOno* ($P < 0.01$). Activity under condition *NOunc*, in turn, was significantly elevated over that under condition *NOno*, $P < 0.01$. In addition, a significant effect was observed across trials, with a decrease from trial 1, $x = 8.69$, to trial 2, $x = 7.1$; $P < 0.01$.

Chin EMG activity

A significant main effect for CDC, $F(4,164) = 17.09$, $P < 0.001$, and for its interaction with trial number, $F(5,180) = 2.88$, $P < 0.05$, were overshadowed by a significant second-order interaction among CDC, trial number, and letter-set size, $F(5,190) = 2.85$, $P < 0.05$. Tests of simple main effects revealed a significant effect for CDC for $q = 2$ at trial 1, $F(4,354) = 3.22$, $P < 0.05$ (based on a pooled error term according to procedures of Kirk, 1968, chap. 8, 1982, chap. 11). Means across the levels of CDC for this trial—letter-set-size combination are presented in the middle panel

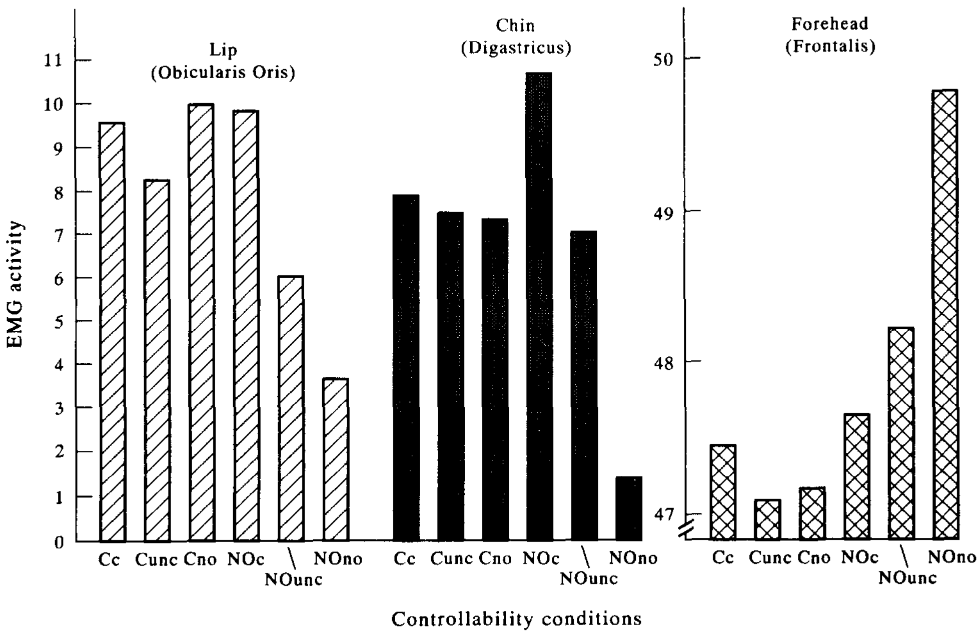

Fig. 1

of Fig. 1. Paired comparisons indicated that the mean for condition *NOno* was significantly less than those for the remaining conditions ($P < 0.01$).

Medial frontalis EMG activity

*S*s were 52 male and 52 female undergraduates from the same as the present population (Morrison *et al.*, 1988). They were selected from an undergraduate *S* pool, using methods of recruitment identical to the present ones (participation met psychology course credit requirements). In addition, experimentation with each sample took place during the same period of the academic year. No longitudinal cohort confounds that might affect the results were identified.

Medial frontalis EMG activity was recorded using surface electrodes placed approximately midway between each eyebrow and the hairline. Scoring duplicated that for lip and chin EMG activity. Baseline EMG values were higher for females, $x = 49.28$, than for males, $x = 40.577$, $F(1,100) = 14.10$, $P < 0.01$. The mean EMG activity for females during the task trials remained significantly higher than that for males, after covariance adjustment for baseline values, 51.25 vs 44.56, $P < 0.01$. Elevated medial frontalis EMG among females has been a fairly common finding in this and other laboratories (see, e.g. Collins & Frankenhaeuser, 1978; Dobson & Neufeld, 1981). Noteworthy regarding the present purposes was the significant effect of CDC, *F* (*conservative* $df = 1,100) = 4.49$, $P < 0.05$, which was stable across the remaining factors, and their combinations, $P > 0.10$. The right hand panel of Fig. 1 presents the mean scores for medial frontalis EMG activity over the levels of CDC. Paired comparisons again were undertaken using Neuman-Keuls procedures; conservative and liberal degrees of freedom gave the same pattern of results. The EMG activity under each of the conditions *Cc* through *NOc* was less than that of condition *NOno*, $P < 0.01$, as was that of condition *NOunc*, $P < 0.05$.

Mention should be made that medial frontalis muscle response may be inhibited during cognitive processing and task involvement (Lawler, Obrist & Lawler, 1976; Obrist, Webb & Sutterer, 1969). Thus, increased frontalis response values under conditions of dimished control may indicate disinhibition, rather than response to increased aversive-event probability. Note, however, that mean values for all conditions, including the first 4, where control was available, exceeded those of baseline. This observation indicates that the configuration of medial frontalis EMG activity was indicative of response to the relative presence of threat, over and against muscle activity (dis)inhibition.

HR ACC

Significant main effects of CDC, $F(5,195) = 13.86$, $P < 0.001$, and of trials, $F(1,39) = 25.44$, $P < 0.001$, were qualified by their significant interaction, $F(5,195) = 2.34$, $P < 0.05$. Simple main effects of CDC were significant at each trial, $P < 0.01$. Figure 2 presents mean values across levels of CDC separately for trials 1 and 2. At trial 1, values for *Cc* and *NOc* significantly exceeded that for *NOno*, $P < 0.01$; also, the mean for condition *Cc* significantly exceeded those of *Cunc*, *Cno*, and *NOunc* $P < 0.01$. At trial 2, the means for conditions *Cc*, *Cunc*, *Cno*, and *NOc* significantly exceeded those of conditions *NOunc* and *NOno*, $P < 0.01$.

HR DEC

The main effect of CDC was highly significant, $F(5,192) = 17.56$, $P < 0.001$. Means appear in Fig. 3. A greater decelerative response occurred to conditions *Cc* through *NOc*, than to conditions *NOunc* and *NOno*, $P < 0.01$; also *Cc* significantly differed from *Cno*, $P < 0.05$.

SC

The main effect of CDC was highly significant, $F(5,192) = 10.92$, $P < 0.001$, but was qualified by its interaction with letter set size, $F(5,195) = 3.33$, $P < 0.01$. Figure 4 displays the means for combinations of CDC—letter-set size levels. Each simple main effect of CDC was significant, $P <$ at least 0.05. For $q = 2$, the means for conditions *Cc*, *Cunc*, and *Cno* each significantly exceeded the

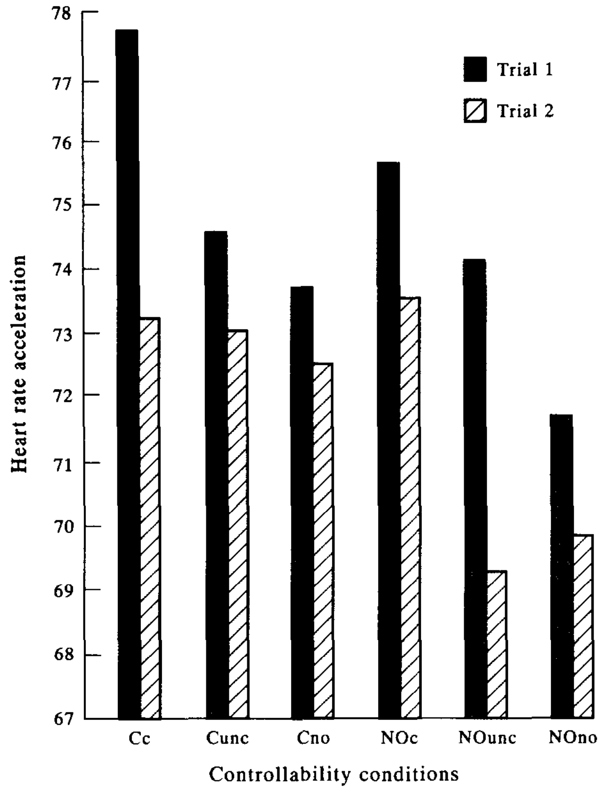

Fig. 2

means for conditions *NOunc* nd *NOno*, $P < 0.001$. Other significant differences involved condition *NOc*, both as compared to *NOunc*, and to *NOno*, $P < 0.05$, as well as *Cc* as compared to *Cno* and *NOc*, $P < 0.01$. For $q = 4$, means for conditions *Cc* through *NOc* were significantly higher than that of *NOunc*, $P < 0.05$.

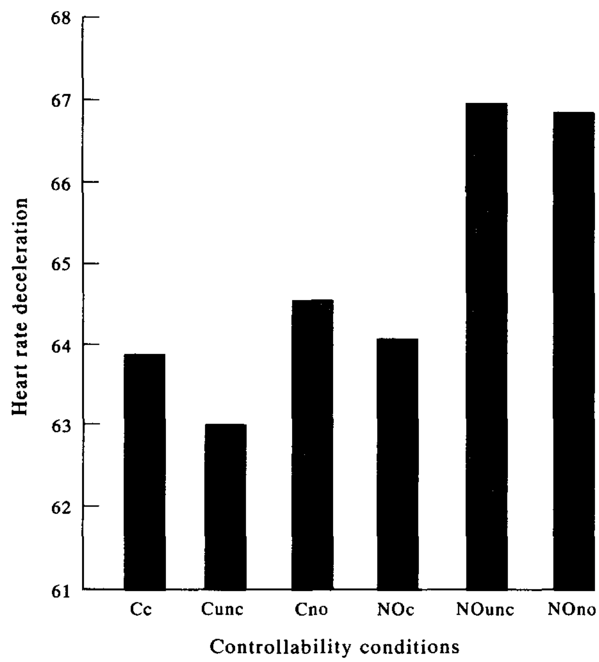

Fig. 3

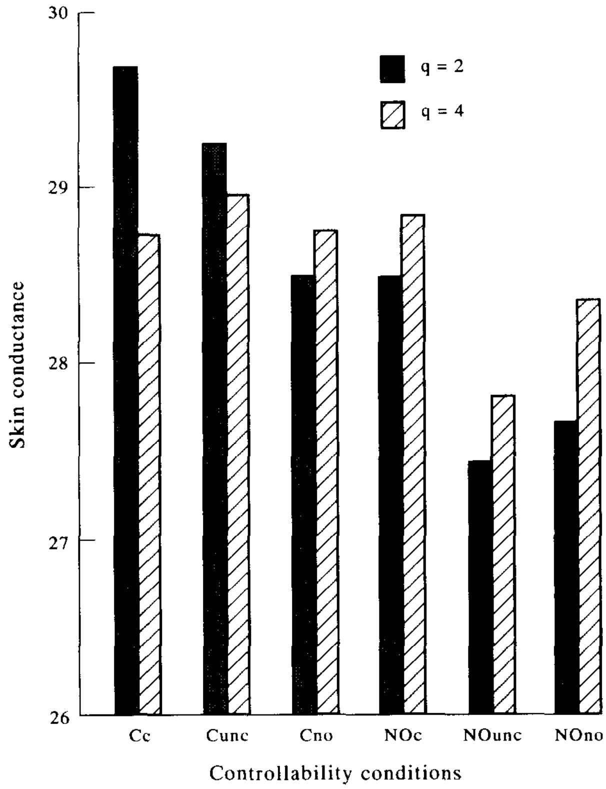

Fig. 4

A significant effect for trials indicated significantly higher conductance during the second, $x = 29.62$, than during the first, $x = 27.38$, trial, $P < 0.01$.

Stress ratings

A significant main effect for CDC, $F(3,112) = 34.81$, $P < 0.001$, was qualified by first-order interactions, both with trials, and with letter set size, $P < 0.05$ in each case (see Fig. 5). Simple main effects of CDC were obtained both for $q = 2$, and $q = 4$, $P < 0.01$. In the case of $q = 2$, means for *Cc*, through *NOc* each significantly exceeded those for *NOunc* and *NOno*, as they did for $q = 4$, $P < 0.01$. Furthermore, in the case of $q = 4$, condition *Cc*'s mean was significantly higher than was condition *Cno*'s, $P < 0.05$.

Simple main effects of CDC were significant both for the first, and second trials, $P < 0.01$.

Response time

A main effect of CDC, $F(3,123) = 96.53$, $P < 0.001$, and of letter size, $F(4,152) = 4.31$, $P < 0.01$, were qualified by a significant second-order interaction of these factors with trial number, $F(4,152) = 6.79$, $P < 0.001$. The 24 means representing this interaction are plotted in Fig. 6.

The simple interaction of CDC and letter set size was significant for trials 1 and 2, $P < 0.01$. Analyses of simple simple main effects of CDC for each of the 4 letter-set—trial level combinations revealed significant effects in each case, $P < 0.01$.

Noise probability for selected/assigned items

A main effect of CDC, $F(4,150) = 26.71$, $P < 0.001$, was accompanied by significant interactions of this factor with each of trial number and letter-set size, $P < 0.01$. In addition, the second order interaction among these factors was significant, $F(3,123) = 6.98$, $P < 0.001$. Tests of simple simple main effects of CDC were significant for each of the 4 combinations of trial and set-size levels, $P < 0.01$. Table 3 presents means for the relevant factorial combinations of levels.

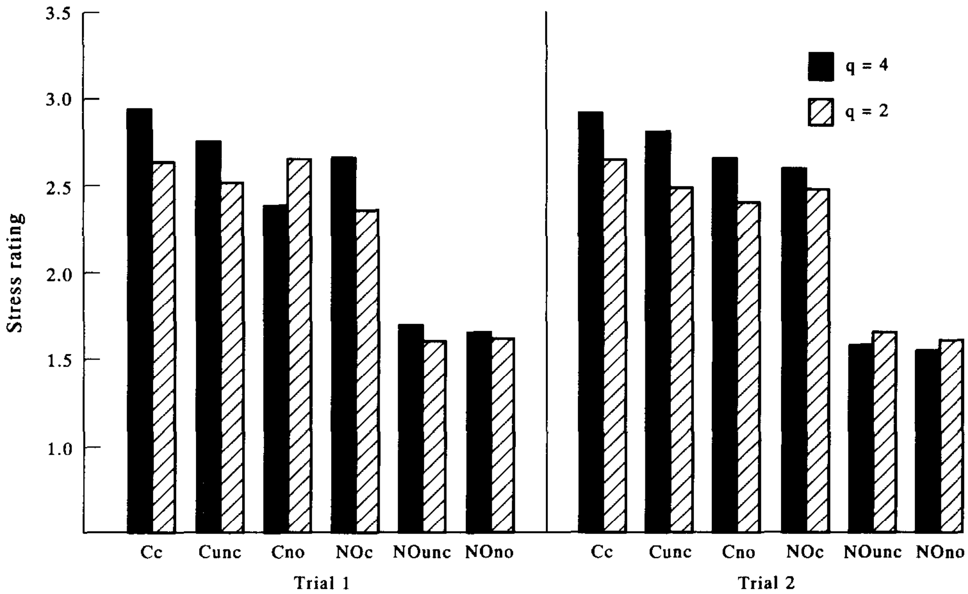

Fig. 5

DISCUSSION

The paradigm of coping through decisional control employed in this study afforded a strong test of the dissociation between locations of the facial musculature regarding sensitivity to alternate sources of stress. Cognitive work associated with covert coping activity, on the one hand, and relative threat of aversive stimulus events, on the other, were tracked by different muscle groupings. Strength of the test derived from the inverse relation between these sources of stress across the

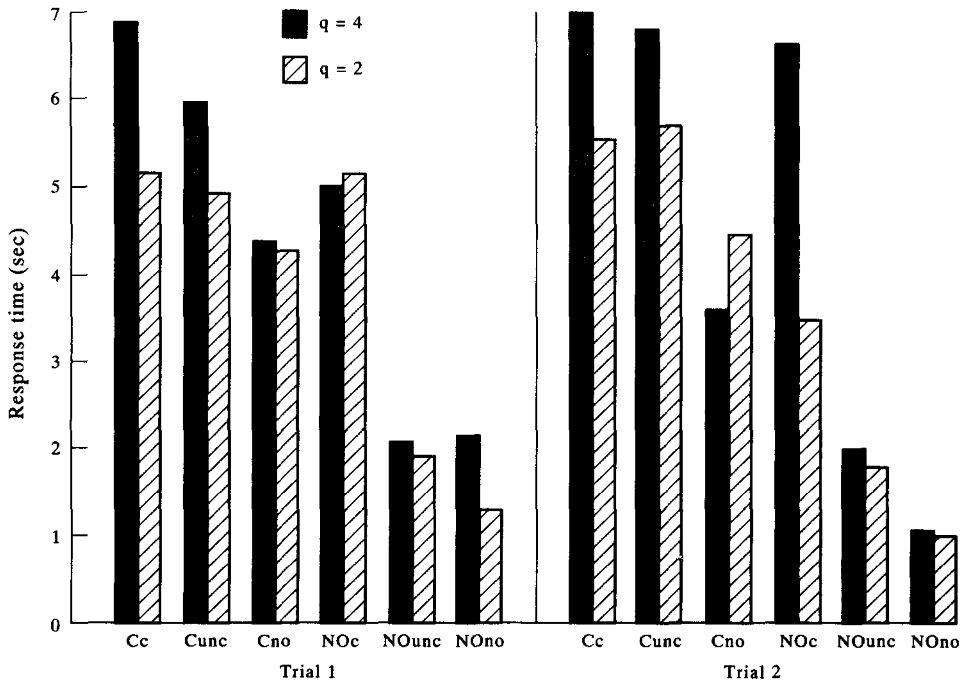

Fig. 6

Table 3. Noise probabilities for selected/assigned items

	Conditions of decisional control					
	Cc	*Cunc*	*Cno*	*NOc*	*NOunc*	*NOno*
Trial 1						
$q = 2$	0.35[a]	0.44[b]	0.43[b]	0.56[c]	0.45[b]	0.51[bc]
$q = 4$	0.34[a]	0.49[b]	0.52[b]	0.37[a]	0.51[b]	0.53[b]
Trial 2						
$q = 2$	0.35[a]	0.43[b]	0.55[c]	0.41[b]	0.48[bc]	0.48[bc]
$q = 4$	0.35[a]	0.50[b]	0.47[b]	0.42[b]	0.50[b]	0.44[b]

Row values not sharing superscripts are significantly different, $P <$ at least 0.05.

paradigm's conditions of decisional control; both sensitivity to one source of stress, and specificity to that source, were necessary for the patterns of EMG activity from the two recording areas to diverge. The condition with the least judgmental requirements, also being one of the two with the highest threat of aversive event outcome (*NOno*), for example, led to the lowest amount of lip and chin EMG activity, despite activating the highest amount of medial frontalis response; conversely, the condition harbouring the least threat of aversive event outcome, also being one of the two with the most judgmental requirements, (*Cc*), substantially and significantly elevated lip and chin EMG activity, and decreased medial frontalis activity.

It is possible that suppression of medial frontalis EMG activity takes place to facilitate information intake and concentration (Lawler *et al.*, 1976; Obrist *et al.*, 1969; Pribram & McGuinnes, 1975). Thus, the increased activity associated with reduced availability of decisional control may reflect a disinhibition of medial frontalis EMG activity, rather than response to increased threat of aversive event outcomes. There are at least two arguments against this interpretation. The first is that mean values for this response modality across the first four cognitively demanding situations, *Cc* through *NOc*, each were above, rather than below, mean baseline values (Morrison, 1985). The second is that Cacioppo *et al.* (1986) found that this area, along with the corrugator supercilia (brow), was relatively responsive to the presentation of unpleasant sounds and affectively negative photographs. On balance, although reduction of medial frontalis EMG activity may abet information processing, the inference that threat of aversive-event outcomes contributed to its increase in the present case appears warranted.

We turn our attention now to sympathetic activation, as evinced in HR and SC. HR ACC tended to be highest in the cognitively demanding condition, *Cc*, and lowest in the condition with the lowest outcome set size, *NOno*. Compatible with the present paradigmatic context, HR ACC has been linked to performance of concentration-demanding tasks, including those affording reduction of aversive-event threat (Campos & Johnson, 1967; Houston, 1972). More generally, it has been identified with "active coping" in the form of meeting task demands that mediate control over environmental events (Light & Obrist, 1980; Obrist, Gaebelein, Teller, Langer, Grignolo, Light & McGubbin, 1978).

A net decrease in the HR DEC response—an increase in mean values—took place as outcome set size decreased. Reduction in decisional control necessitated progressively less visual scanning of accessible alternatives. Accordingly, HR DEC has been aligned with "environmental intake" (Lacey, 1972), or attention to external stimulation (Epstein & Clark, 1970; Graham & Clifton, 1968; Lacey, 1972). Taken together, the measured cardiac responses essentially concur with the view that decisional control, as operationalized in this paradigm, brings into play visual scanning of the available alternatives, and encoding of these alternatives with respect to their memorial relative frequencies of stressor occurrence.

SC also underwent a net decline with an overall decrease in outcome set size. Cognitive activity has been shown to increase values of SC (Deswart & Das-Small, 1976; Grings, 1973; Mikhail, 1981), particularly when it involves controllable tasks invoking effortful responding (Manuck, Harvey, Lechleiter & Neal, 1978; Solomon, Holmes & McCaul, 1980).

On balance, mobilization of the cardiac and SC responses was interpreted as facilitating information processing involved in implementing available decisional control. Additional sympathetic activation may have been generated by the stressing properties of the cognitive transactions themselves (Gaines, Smitth & Skolnick, 1977; Roessler, 1973); the pattern of reported subjective stress indicated that those transactions were stressing in their own right.

Returning to reponses of the facial musculature, lip and chin EMG activity during encounters of laboratory stressors represent potentially useful measures of coping involving cognitive activity. Such coping includes decisional control, and "cognitive control". The latter entails "comforting redefinition" of stressing situations into subjectively more favorable terms, and taking cognizance of one's own abilities for dealing with impending events (Averill, 1973; Lazarus, 1966; Thompson, 1981). Past laboratory measures of coping typically have been of a self-report format (reviewed in Neufeld, 1989). Occasionally, they have comprised the configuration of reported stress, as set against autonomic responses, such as HR or SC; relative elevation in the latter, *vis-a-vis* verbally stated levels of stress arousal, have been thought to be indicative of coping through "denial of stress arousal" (Lazarus & Averill, 1972; Neufeld, 1975). Measures such as these tend to provide summary indexes of coping across the experimental session, whereas lip and chin EMG activity affords ongoing measurement of coping, and of changes in level of coping response, over the session.

By way of extension, measures of lip and chin EMG activity may also be of value in selected field settings where available avenues of coping are relatively rich in information processing. For example, certain psychological preparations for minor medical procedures involve to varying degrees the provision of information regarding the procedures themselves, and the sensations they are expected to produce (Ludwick-Rosenthal & Neufeld, 1988). Monitoring of lip and chin EMG activity during periods of information provision may be used to augment psychometric and behavioural-avoidance measures of individual differences in preference for the provided information (Krantz, Baum & Wideman, 1980; Miller, 1981; cf. Ludwick-Rosenthal & Neufeld, 1993).

Finally, a further word is in order regarding the concept of "cognitive work done", with respect to measures of speech musculature activity. Formal definitions of this concept take the form of mathematical functions that increase with the rate per unit time, or intensity, of cognitive transactions, and with the duration of these transactions (Townsend & Ashby, 1978). The present measures of EMG activity of the monitored speech musculature may be thought of as representing empirical correlates of the above rate, or intensity, parameter; the present measure of response time, in turn, essentially may be seen as reflecting the latency parameter. Increases both in response time and lip and chin EMG activity by and large were associated with conditions of greater decisional control, and their corresponding outcome set size values. In other words, greater decisional control overall was associated with more cognitive work, as specified in this way.

The concept of cognitive work, in turn, implicates that of "cognitive efficiency" (Wishner, 1955), as follows. Completing the operations defined by some focal task can be accomplished with varying amounts of cognitive work; as the latter increases, efficiency decreases (cf. Eysenck, 1979, 1989). Individual differences in such efficiency may contribute to individual differences in relative preference for decisional control as a coping option (cf. Gal & Lazarus, 1975; Morrison *et al.*, 1988; Neufeld, 1990b; Thompson, 1981). Increased efficiency implies reduced cognitive effort in implementing available decisional control, and as such, may increase the appeal of this mode of coping for some individuals.

Furthermore, to the above operationalization of cognitive work, other measures of intensity or rate of cognitive transactions, used in connection with the efficiency concept, have included positron emission tomography of cerebral glucose metabolic rates (Haier, Siegel, Tang, Abel & Buchsbaum, in press). It has been shown, for example, that metabolic rate during the computer game, TETRIS, decreases to a greater degree after practice, for more intelligent *S*s. EMG activity of the facial musculature may represent a highly competitive measure of the cognitive-transaction rate. First, it is less expensive and less time consuming than are measures of glucose metabolic rate; second, as overt behaviour, although polygraphically measured, it may be less affected by sources of variance extraneous to cognitive activity *per se*; and, third, it can be monitored continuously.

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REFERENCES

Averill, J. R. (1973). Personal control over aversive stimuli and its relationship to stress. *Psychological Bulletin, 80,* 286–303.

Balshan, L. P. (1962). Muscle tension and personality in women. *Archives of General Psychiatry, 7,* 436–448.

Boik, R. (1988). The mixed model for multivariate repeated measures: Validity conditions, and approximate test. *Psychometrika*, *53*, 469–486.
Cacioppo, J. T. & Petty, R. E. (1979a). Attitudes and response: An electrophysiological approach. *Journal of Personality and Social Psychology*, *37*, 2182–2199.
Cacioppo, J. T. & Petty, R. E. (1979b). Lip and nonpreferred forearm EMG activity as a function of orienting task. *Biological Psychology*, *9*, 103–113.
Cacioppo, J. T. & Petty, R. E. (1981a). Electromyographic specificity during convert information processing. *Psychophysiology*, *18*, 518–523.
Cacioppo, J. T. & Petty, R. E. (1981b). Electromyograms as measures of extent and affectivity of information processing. *American Psychologist*, *36*, 441–457.
Cacioppo, J. T., Marshall-Goodell, B. & Dorfman, D. D. (1983). Skeletomuscular patterning: Topographical analysis of the integrated electromyogram. *Psychophysiology*, *20*, 269–283.
Cacioppo, J. T., Petty, R. E. & Marshall-Goodell, B. S. (1984). Electromyographic specificity during simple physical and attitudinal tasks: Location and topographical features of integrated EMG responses. *Biological Psychology*, *18*, 85–121.
Cacioppo, J. T., Petty, R. E. & Morris, K. J. (1985). Semantic, evaluative, and self-referent processing: Memory, cognitive effort, and somatovisceral activity. *Psychophysiology*, *22*, 371–384.
Cacioppo, J. T., Petty, R. E., Losch, M. E. & Kim, H. S. (1986). Electromyographic activity over facial muscle regions can differentiate the valence and intensity of affective reactions. *Journal of Personality and Social Psychology*, *50*, 260–268.
Campos, J. & Johnson, H. (1967). Affect, verbalization, and directional fractionation of autonomic responses. *Psychophysiology*, *3*, 285–290.
Collins, A. & Frankenhaueser, M. (1978). Stress response in male and female engineering students. *Journal of Human Stress*, *4*, 43–48.
Davidson, P. O. & Neufeld, R. W. J. (1974). Response to pain and stress: A multivariate analysis. *Journal of Psychosomatic Research*, *18*, 25–32.
Deswart, J. H. & Das-Small, E. A. (1976). Relationship between skin conductance response, heart rate and information processing. *Biological Psychology*, *4*, 41–49.
Dobson, K. & Neufeld, R. W. J. (1981). Sources of differential stress response associated with psychometrically-designated anxiety proneness. *Journal of Personality and Social Psychology*, *40*, 951–961.
Einhorn, H. J. & Hogarth, R. M. (1978). Confidence in judgment: Persistence of the illusion of validity. *Psychological Review*, *85*, 395–416.
Ekman, P. & Friesen, W. V. (1978). *Facial coding action system (FACS): A technique for the measurement of facial actions.* Palo Alto, CA: Consulting Psychologists Press.
Endler, N. S. & Magnusson, D. (1977). The interaction model of anxiety: An empirical test in an examination situation. *Canadian Journal of Behavioural Science*, *9*, 101–107.
Epstein, S. & Clark, S. (1970). Heart rate and skin conductance during experimentally induced anxiety: Effects of anticipated intensity of noxious stimulation and experience. *Journal of Experimental Psychology*, *84*, 105–112.
Estes, W. K. (1975). Structural aspects of associative models for memory. In Cofer, C. N. (Ed.), *The structure of human memory*. San Francisco, CA: Freeman.
Estes, W. K. (1976). The cognitive side of probability learning. *Psychological Review*, *83*, 37–64.
Estes, W. K. (1977). Some functions of memory in probability and choice behavior. In Bower, G. H. (Ed.), *The psychology of learning and motivation* (Vol. 10, pp. 1–45). New York: Academic Press.
Eves, F. F. & Gruzelier, J. H. (1984). Novel effects of high intensity auditory stimulation on the cardiac response. *Biological Psychology*, *18*, 274–275.
Eysenck, M. W. (1979). Anxiety, learning and memory: A reconceptualization. *Journal of Research in Personality*, *13*, 363–385.
Eysenck, M. W. (1989). Personality, stress arousal, and cognitive processes in stress transactions. In Neufeld, R. W. J. (Ed.), *Advances in the investigation of psychological stress* (pp. 133–160). New York: Wiley.
Fisher, S. (1986). *Stress and strategy*. London: Lawrence Erlbaum Associates Ltd.
Gaines, L. S., Smith, B. D. & Skolnick, B. (1977). Psychological differentiation, event uncertainty, and heart rate. *Journal of Human Stress*, *3*, 11–25.
Gal, R. G. & Lazarus, R. S. (1975). The role of activity in anticipating and confronting stressful situations. *Journal of Human Stress*, *4*, 4–20.
Geer, J. H. & Klein, K. (1969). Effects of two independent stresses upon autonomic responding. *Journal of Abnormal Psychology*, *74*, 237–241.
Glass, D. C. (1977). *Behavior patterns, stress, and coronary disease*. New Jersey: John Wiley & Sons.
Graham, F. K. & Clifton, R. K. (1968). Heart-rate change as a component of the orienting response. *Psychological Bulletin*, *65*, 305–320.
Grings, W. W. (1973). Cognitive factors in electrodermal conditioning. *Psychological Bulletin*, *79*, 200–210.
Haier, R. J., Siegel, B., Tang, C., Abel, L. & Buchsbaum, M. S. (1992). Intelligence and changes in regional cerebral glucose metabolic rate following learning. *Intelligence 16*, 415–426.
Hamilton, V. (1980). An information processing analysis of environmental stress and life crises. In Sarason, I. G. & Spielberger, C. D. (Eds), *Stress and anxiety* (Vol. 7, pp. 13–30). Washington: Hemisphere.
Hockey, G. R. J., Gaillard, A. W. K. & Coles, M. G. H. (1986). (Eds), *Energetics and human information processing*. Boston: Martinus Nijyoff Publishers.
Houston, B. K. (1972). Control over stress, locus of control and response to stress. *Journal of Personality and Social Psychology*, *21*, 249–255.
Izard, C. E. (1971). *The face of emotion*. New York: Appleton-Century-Crofts.
Kirk, R. E. (1968). *Experimental design: Procedures for the behavioral sciences*. Monterey: Brooks/Cole.
Kirk, R. E. (1982). *Experimental design: Procedures for the behavioral sciences* (2nd Edn). Monterey: Brooks/Cole.
Krantz, D. S., Baum, A. & Wideman, M. (1980). Assessment of preferences for self-treatment and information in health care. *Journal of Personality and Social Psychology*, *39*, 977–990.

Lacey, J. I. (1972). Some cardiovascular correlates of sensori-motor behavior: Examples of visceral afferent feedback. In Hockman, C. H. (Ed.), *Limbic systems mechanisms and autonomic function*. Springfield: C. C. Thomas.

Lawler, K. A., Obrist, P. A. & Lawler, J. E. (1976). Cardiac and somatic response patterns during a reaction time task in children and adults. *Psychophysiology, 13*, 448–455.

Lazarus, R. S. (1966). *Psychological stress and the coping process*. New York: McGraw-Hill.

Lazarus, R. S. (1975). A cognitively oriented psychologist looks at biofeedback. *American Psychologist, 30*, 553–560.

Lazarus, R. S. & Averill, J. R. (1972). Emotion and cognition: With special reference to anxiety. In Spielberger, C. D. (Ed.), *Anxiety: Current trends in theory and research*. New York: Academic Press.

Lefave, M. K. & Neufeld, R. W. J. (1980). Anticipatory threat and physical-danger trait anxiety: A signal-detection analysis of effects on autonomic responding. *Journal of Research in Personality, 14*, 283–306.

Light, K. C. & Obrist, P. A. (1980). Cardiovascular responses to stress: Effects of opportunity to avoid, shock experience, and performance feedback. *Psychophysiology, 17*, 243–252.

Ludwick-Rosenthal, R. & Neufeld, R. W. J. (1988). Stress management during noxious medical procedures: An evaluative review of outcome studies. *Psychological Bulletin, 104*, 326–342.

Ludwick-Rosenthal, R. & Neufeld, R. W. J. (1993). Preparation for undergoing an invasive medical procedure: Interacting effects of information and coping style. *Journal of Consulting and Clinical Psychology, 61*, 156–164.

Manuck, S. B., Harvey, A. H., Lechleiter, S. L. & Neal, K. S. (1978). Effects of coping on blood pressure responses to threat of aversive stimulation. *Psychophysiology, 15*, 544–549.

Martin, B. & Sroufe, L. A. (1970). Anxiety. In Costello, C. G. (Ed.), *Symptom of psychopathology*. New York: Wiley.

Mikhail, A. (1981). Stress. A psychophysiological conception. *Journal of Human Stress, 7*, 9–15.

Miller, S. M. (1981). Predictability and human stress: Towards a clarification of evidence and theory. In Berkowitz, L. (Ed.), *Advances in experimental social psychology, Vol. 14* (pp. 203–256). New York: Academic Press.

Morrison, M. S. (1985). Information synthesis and potentially controllable situations: Implications for stress relevant appraisals. Ph.D. dissertation, Department of Psychology, University of Western Ontario.

Morrison, M. S., Neufeld, R. W. J. & Lefebvre, L. A. (1988). The economy of probabillistic stress: Interplay of controlling activity and threat reduction. *British Journal of Mathematical and Statistical Psychology, 41*, 155–177.

Mothersill, K. & Neufeld, R. W. J. (1985). Probability learning and coping in dysphoria and obsessive-compulsive tendencies. *Journal of Research in Personality, 19*, 152–165.

Mothersill, K., Dobson, K. & Neufeld, R. W. J. (1986). The interactional model of anxiety: An evaluation of the differential hypothesis. *Journal of Personality and Social Psychology, 51*, 640–648.

Neufeld, R. W. J. (1975). Effects of cognitive appraisal on d′ and response bias to experimental stress. *Journal of Personality and Social Psychology, 31*, 735–743.

Neufeld, R. W. J. (1976). Evidence of stress as a function of experimentally-altered appraisal of stimulus aversiveness and coping adequacy. *Journal of Personality and Social Psychology, 33*, 632–646.

Neufeld, R. W. J. (1978). Veridicality of cognitive mapping of stressor effects: Sex differences. *Journal of Personality, 3*, 85–121.

Neufeld, R. W. J. (1982). On decisional processes instigated by threat: Some possible implications for stress-related deviance. In Neufeld, R. W. J. (Ed.), *Psychological stress and psychopathology*. New York: McGraw-Hill.

Neufeld, R. W. J. (1989). Methodological aspects of laboratory studies of stress. In Newfeld, R. W. J. (Ed.), *Advances in the investigation of psychological stress*. New York: John Wiley & Sons.

Neufeld, R. W. J. (1990a). Coping with stress, coping without stress, and stress with coping: On inter-construct redundancies. *Stress Medicine, 6*, 117–125.

Neufeld, R. W. J. (1990b). Morrison, Neufeld & Lefebvre's game theoretic approach to stress and decisional control: Some further mathematical results. Research Bulletin No. 688, Department of Psychology, University of Western Ontario, London, Canada.

Neufeld, R. W. J. & Davidson, P. O. (1974a). Sex differences in stress responses: A multivariate analysis. *Journal of Abnormal Psychology, 83*, 178–185.

Neufeld, R. W. J. & Davidson, P. O. (1974b). Dimensionality of subjective responses to a selection of complex aversive stimuli. *Canadian Journal of Behavioral Science, 6*, 258–269.

Neufeld, R. W. J. & Herzog, H. (1983). Acquisition of probabilities in anticipatory appraisals of stress. *Personality and Individual Differences, 4*, 1–17.

Neufeld, R. W. J. & Paterson, R. J. (1989). Issues concerning control and its implementation. In Neufeld, R. W. J. (Ed.), *Advances in the investigation of psychological stress*. New York: John Wiley & Sons.

Obrist, P. A. (1981). *Cardiovascular psychophysiology: A perspective*. New York: Plenum.

Obrist, P. A., Webb, R. A. & Sutterer, J. R. (1969). Heart-rate and somatic changes during aversive conditioning and a simple reaction time task. *Psychophysiology, 5*, 696–723.

Obrist, P. A., Gaebelein, C. J., Teller, E. S., Langer, A. W., Grignolo, A., Light, K. C. & McCubbin, J. A. (1978). The relationship among heart rate, carotid dP/dt, and blood pressure in humans as a function of type of stress. *Psychophysiology, 15*, 102–115.

Paterson, R. & Neufeld, R. W. J. (1987). Clear danger: The perception of threat when the parameters are known. *Psychological Bulletin, 101*, 404–416.

Patrick, C. J., Craig, K. D. & Prkachin, K. M. (1986). Observer judgments of acute pain: Facial action determinants. *Journal of Personality and Social Psychology, 50*, 1291–1298.

Pribram, K. H. & McGuinness, D. (1975). Arousal, activation, and effort in the control of attention. *Psychological Review, 82*, 116–149.

Prkachin, K. J., Currie, N. A. & Craig, K. D. (1983). Judging of nonverbal expressions of pain. *Canadian Journal of Behavioural Sciences, 15*, 409–421.

Rappaport, A. (1983). *Mathematical models in the social and behavioral sciences*. New York: Wiley.

Roessler, R. (1973). Personality, psychophysiology, and performance. *Psychophysiology, 10*, 315–327.

Schonpflug, W. (1986). Behavior economics as an approach to stress theory. In Appley, M. H. & Trumbull, R. (Eds), *Dynamics of stress: Physiological, psychological, and social perspectives*. New York: Plenum Press.

Solley, C. M. & Thetford, P. E. (1967). Skin potential responses and the span of attention. *Psychophysiology, 3*, 397–402.

Solomon, S., Holmes, D. S. & McCaul, K. D. (1980). Behavioral control over aversive events: Does control that requires effort reduce anxiety and physiological arousal? *Journal of Personality and Social Psychology*, *39*, 729–736.

Thompson, S. (1981). Will it hurt less if I can control it? A complex answer to a simple question. *Psychological Bulletin*, *90*, 89–101.

Townsend, J. T. (1971). Theoretical analysis of an alphabetic confusion matrix. *Perception and Psychophysics*, *9*, 40–50.

Townsend, J. T. & Ashby, F. G. (178). Methods of modeling capacity in simple processing systems. In Castellan, J. & Restle, F. (Eds), *Cognitive theory* (Vol. 3). Hillsdale: Erlbaum.

Voglmaier, M. M., Bruder, G. E., Hakerem, G. & Tenke, C. E. (1991). Facial electromyography in anxious and nonanxious depression: Relation to auditory perceptual asymmetry. Paper presented at the *Society for Research in Psychopathology Sixth Annual Meeting*, Cambridge, MA.

Wishner, J. (1955). The concept of efficiency in psychological health and psychopathology. *Psychological Review*, *62*, 69–80.

Wright, R. A. (1987). Coping difficulty, energy mobilization, and appraisals of a stressor: Introduction of a theory and a comparison of perspectives. In Snyder, C. R. & Ford, C. E. (Eds), *Coping with negative life events: Clinical and social psychological perspectives*. New York: Plenum Press.

Zajonc, R. B. (1985). Emotional and facial efference: A theory reclaimed. *Science*, *228*, 15–21.