Comparability of EDA effects obtained with constant-current skin resistance and constant-voltage skin conductance methods

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EDA was recorded from one group of subjects by using a standard constant-voltage method and from another group by using polarizable electrodes, a hypertonic electrolyte, and a constant-current method with ac coupled output. The robustness of stimulus-response relationships for EDA was examined by comparing the groups over (counterbalanced) blocks of 10 auditory and 10 visual stimuli of low intensity. Both raw and range-corrected EDA measures showed significant novelty and modality effects without group differences, and high between-group correlations over means ($r \geq .87$). These results indicate that SRR measures from field-type studies may validly represent EDA expected from a more rigorous application of SCR techniques. Respiratory pause was also examined in both groups and found to reflect only novelty changes. This lack of covariation with EDA is contrary to unitary OR theory but compatible with recent proposals of preliminary processes in OR elicitation.

Phasic changes in electrodermal activity (EDA) may be derived from two different systems. The older system, employing a constant current, leads directly to the skin resistance response (SRR), while the newer system, utilizing a constant voltage, directly generates the skin conductance response (SCR). The transition between these methods, given initial impetus by the theoretical and technical arguments of Edelberg (1967, 1972) and Lykken and Venables (1971), remains incomplete, and studies presenting results derived from the different methods are still appearing in the literature.

The question of the comparability of such results is of continuing interest, as reflected in a recent study by Boucsein and Hoffmann (1979). These authors made a direct comparison of simultaneous SCR and SRR measures obtained (by constant-voltage and constant-current devices, respectively) from a group of subjects in response to white-noise stimuli ranging in intensity from 60 to 110 dB. They found no difference in raw amplitudes (SCRs were converted to SRR units for this comparison), but reported a significant difference between range-corrected amplitudes obtained following the Lykken and Venables (1971) procedure. This difference in range-corrected amplitudes was most surprising, particularly since there was no difference in raw scores, and it is deserving of further investigation. One variable that might be implicated in such a result is the relatively high range of stimulus intensity used in their study, so it is necessary to investigate comparability of these measures with lower intensities such as those com-

patible with elicitation of the orienting response (OR) of Sokolov (1963).

Three other sources of variation in recording technique merit attention in any consideration of the robustness of EDA measures: electrodes, electrolytes, and coupling. The first two often depart from the ideal in field-type studies: for example, Dawson (1980) employed stainless steel electrodes and an unreported electrolyte in a deception-detection study. Such polarizable electrodes significantly affect the measurement of tonic skin resistance, but not the phasic SRR. Thus, although unsuitable if SCRs are to be calculated from constant-current measures of EDA (a fairly common procedure), their use is adequate for SRR measurement. The same argument applies to the use of nonisotonic electrolytes as the contact medium between electrode and epidermis. Even hypertonic solutions designed to depolarize the skin and reduce skin resistance, such as those commercially formulated for EKG use, may be adequate for the measurement of SRR *per se*. However, SCRs derived from these (e.g., Sagberg, 1980) are of doubtful validity¹ and should be interpreted cautiously. Thirdly, the coupling employed in the recording of the response may affect response amplitudes. While most modern studies employ dc coupling (which is again necessary if constant-current devices are to yield sufficient information to compute SCR measures), the consequent necessity of frequently zeroing the base level during a recording session may impose undue demands upon the experimenter. Work from this laboratory comparing a number of OR indicators (e.g., Barry, 1977) or involving autistic children (in preparation) has used ac coupling of SRR to avoid such problems. While such

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ac coupling would be expected to reduce, slightly, SRR amplitudes, the impact of such a reduction upon the form of stimulus-response relationships is unknown.

Thus, this study was designed to test the robustness of phasic EDA measures in an OR context. SRR was recorded from one group of subjects using an ac coupled constant-current method, with polarizable electrodes and a hypertonic electrolyte. SCR was recorded from another group using a dc-coupled constant-voltage method, with standard electrodes and contact medium. Habituation to repeatedly presented auditory and visual stimuli was examined in both groups.²

Finally, respiratory pause was also examined as a function of stimulus novelty and modality. This variable was included because recent work upon the unitary OR concept in this laboratory (e.g., Barry & James, 1981) had indicated that SRR and respiratory pause failed to covary across a range of stimulus parameters, supporting aspects of an alternative concept of preliminary processes in OR elicitation (Barry, 1979).

METHOD

Subjects

Twenty university students, aged 20-25 years, volunteered to participate in the experiment to fulfill a requirement of a course in educational psychology at the University of New South Wales. These were alternately assigned to each experimental group.

Apparatus

Exosomatic electrodermal activity was recorded by either a constant-current or constant-voltage method. The constant-current method employed a pair of stainless steel electrodes of size 3 cm × 2 cm and Biocom Inc. Biogel as the contact medium. Ten microamps were provided through the electrodes by a Stoelting GSR preamplifier, whose output was ac coupled to one channel of a Stoelting Multiscribe. The constant-voltage method employed felt corn pads to limit the contact area to .71 cm² (following Lykken & Venables, 1971), Beckman-type Ag/AgCl electrodes, and .05 M KCl in an inert viscous ointment base as electrolyte. A constant voltage of 1.0 V was applied by a locally produced direct-measuring linear SCR device (following Lowry, 1977), the output of which was dc coupled to a channel on the Multiscribe. Respiration was recorded from a Stoelting bellows pneumograph on another channel of the Multiscribe, and stimulus events were signaled on a third channel. Paper speed was 3 mm/sec.

Visual stimuli, consisting of 10 white squares (luminance 137 cd/m²) on a black background (.6 cd/m²), were presented from an Exidy microcomputer on a small (22.5 × 17.5 cm) video monitor. Stimulus size was 9 × 9 cm, with the square centered upon the screen. Stimulus duration was 2.0 sec, with interstimulus intervals varying randomly among 30, 40, and 50 sec. Auditory stimuli were 10 tones presented via circumaural headphones, each of 2,400 Hz and 50 dB re 20 μ N/m², with the same duration and similar interstimulus interval range as the visual stimuli. During the auditory half of the session, a 9-cm-square visual pattern of high complexity was continuously present on the monitor screen. This consisted of some 30,720 elements approximately half of which were either on or off at any time. Randomly positioned elements changed state at an approximate rate of 990 changes/sec. This served to maintain attention on the monitor for the duration

of the study. The innocuous stimuli were chosen to ensure compatibility of the results with OR literature.

Procedure

Alternate subjects were assigned to different groups. Upon arrival at the laboratory, the electrode sites (volar surfaces of the medial phalanges of the second and third fingers of the right hand) were cleansed with alcohol and the appropriate combination of electrodes and electrolyte was fitted. The bellows pneumograph was attached around the subject's chest, and the headphones were adjusted. Physiological recording was carried out in a quiet, darkened room while the subject was seated in a comfortable armchair approximately 70 cm from the monitor. The subjects were instructed to sit quietly and to watch the screen after being informed that the experiment was designed to test their physiological responses to simple stimuli. Within each group, the modality of the initial stimulus block was alternated between visual and auditory.

RESULTS

For both groups, any measurable EDA response with latency between 1 and 5 sec following stimulus onset was scored. The means of these responses within each group are displayed in Figure 1, for each modality, as a function of trial. The vertical axes in this figure were chosen so that the maximum mean responses would appear identical. The effects were analyzed by a three-way ANOVA over group, modality, and trials, with repeated measures on the last two variables (following Poor, 1973). Because of the scale difference, each SCR was divided by .364 μ mho and each SRR by 6.853 k Ω (the largest mean response for each group) so that the relative response levels over modality and trial could be compared. Within trials, only linear and quadratic trends were analyzed to indicate habituation. There was no significant³ group effect [$F(1,18) = 0.00$, $MSe = 3.91$], as expected from the rescaling. The modality effect was significant [$F(1,18) = 8.45$, $MSe = .62$]. There was significant habituation, as indicated by both linear [$F(1,18) = 33.63$, $MSe = .20$] and quadratic [$F(1,18)$

Figure 1. Raw EDA as a function of trial for each modality.

= 30.67, $MSe = .08$] trends over trials. There was a significant difference in the linear trend as a function of modality [$F(1,18) = 6.20$, $MSe = .18$], apparently due to faster habituation with the auditory stimuli (see Figure 1). No other interactions approached significance.

The EDA responses were also range-corrected by dividing each subject's scores by his/her maximum response (following Lykken & Venables, 1971). These values, which are unit-free and range between 0 and 1, were subjected to the same three-way analysis. Mean values for each group are shown in Figure 2. There was no significant group effect [$F(1,18) = 1.16$, $MSe = .39$]. The modality effect apparent in Figure 2 was significant [$F(1,18) = 24.03$, $MSe = .11$]. Significant habituation was reflected in both linear [$F(1,18) = 171.02$, $MSe = .03$] and quadratic [$F(1,18) = 110.12$, $MSe = .02$] trends over trials. These trends differed between the visual and auditory stimuli [$F(1,18) = 13.94$, $MSe = .06$, and $F(1,18) = 11.00$, $MSe = .05$, for linear and quadratic trends, respectively]. This would again appear to be attributable to faster habituation with the auditory stimuli. There were no significant interactions between any of these effects and group, confirming the comparability of the stimulus-response relationships for the range-corrected EDA measures.

The comparability between the EDA measures apparent from the above analyses was quantified by correlating the group means obtained on each of the 20 stimulus presentations. For raw SRR/SCRs, $r = .87$, while for range-corrected EDA measures, $r = .88$.

Finally, respiratory pause was defined as the percentage increase in the period of the respiratory cycle containing the stimulus onset, compared with the prestimulus cycle. This measure appears to capture a short-latency response which reliably reflects stimu-

Figure 3. Respiratory pause as a function of stimulus number for each modality.

lus novelty (e.g., Barry, 1979; Barry & James, 1981). Values of this variable were submitted to the same three-way ANOVA used above; mean responses are shown in Figure 3. There were no significant group [$F(1,18) = 0.00$, $MSe = 482.65$] or modality [$F(1,18) = 1.39$, $MSe = 383.73$] differences. Habituation was indicated by a significant linear trend over trials [$F(1,18) = 13.30$, $MSe = 420.58$]. There were no other significant effects or interactions, indicating that respiratory pause reflected only stimulus novelty. The averaged correlation between the means of respiratory pause and the range-corrected EDA measures over 10 auditory and (separately) 10 visual stimulus presentations was $r = .84$. Over all stimuli, this was reduced to $r = .74$, a reduction attributable to the modality effect found in EDA alone.

DISCUSSION

The primary aim of this study was to investigate the robustness of EDA as an OR indicator. SCRs obtained by recommended modern constant-voltage procedures were compared with ac-coupled SRRs obtained using polarizable electrodes and nonisotonic electrolyte with a constant current, representing field-type procedures. Both the raw EDA responses, rescaled to the same mean relative amplitude, and the range-corrected measures (Lykken & Venables, 1971) showed similar modality and novelty effects within each group of subjects. This compatibility was confirmed by the high between-group correlations of EDA over stimuli for both raw and range-corrected measures. These results indicate that stimulus-response relationships obtained with one procedure are generalizable to the other procedure, emphasizing the robustness of EDA measures in the OR context.⁴ This conclusion applies only to SRRs obtained using

Figure 2. Range-corrected EDA over trials for visual and auditory stimuli.

these field-type procedures, since it has been noted above that the electrodes and electrolyte used do not allow an adequate estimate of skin resistance level as required to convert SRRs to SCRs. It is thus necessary, at least within the present context of a wide range of electrodes, electrolytes, and recording equipment in use, to be more cautious about the validity of derived SCR measures than of SRR measures.

The present results fail to confirm the difference in stimulus-response relationships for range-corrected EDA observed by Boucsein and Hoffman (1979), suggesting that such differences might be associated with their high-intensity stimuli, all of which were above the OR-compatible intensities used in this study. Here the only effect apparent with the use of the Lykken and Venables (1971) range-correction technique was the increase in F values obtained. This is attributable to the reduction in interindividual variance which was the original purpose of the proposed technique.

Finally, respiratory pause was found to reflect novelty only, rather than the novelty and modality effects apparent in EDA. If only novelty changes are involved, both respiratory pause and EDA may be used to index habituation of the OR, but their common variance is reduced if other independent variables are included in the manipulation. This lack of covariation confirms previous findings from this laboratory, and is supportive of a proposed fractionation of the OR (Barry, 1979; Barry & James, 1981) rather than the unitary OR of Sokolov (1963).

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NOTES

1. If the true skin resistance is R_1 and it is reduced by R_2 due to depolarization, an SRR of r Ω involves a change from $(R_1 - R_2)$ to $(R_1 - R_2 - r)$, equivalent to the change from R_1 to $R_1 - r$ in the absence of depolarization. In contrast, the corresponding derived SCRs, $[1/(R_1 - R_2)] - [1/(R_1 - R_2 - r)]$ and $(1/R_1) - [1/(R_1 - r)]$, are *not* equivalent.
2. This between-group design is analogous to a replication study, allowing a realistic examination of whether stimulus-response relationships obtained with one procedure may be expected if the alternative is employed.
3. The significance level adopted in this report is $p < .05$.
4. Such robustness applies only to *phasic* EDA; the present results cannot be generalized to comparisons of absolute electrodermal responses or tonic levels between subjects.

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