Schedule-induced electrodermal responding in children

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Abstract

The current studies were designed to determine whether different intermittent schedules of reinforcement would have a differential effect on the skin conductance responses (SCRs) of children in the 8–12-year-old age range. Results of two experiments indicated that the amplitude of children's SCRs immediately following the occurrence of reinforcement were a function of the schedule of reinforcement, with larger SCRs associated with longer inter-reinforcement intervals. The findings are consistent with the research literature suggesting that long inter-reinforcement intervals can be evocative of aversively motivated emotions, as well as with research on the effects of interstimulus intervals on SCRs. Possible implications for these findings are discussed.

Descriptors: Skin conductance response, Electrodermal response, Children, Aversiveness, Nonreward, Reinforcement schedules, Interstimulus intervals

Electrodermal reactivity to aversive stimulation has played a central role in analyses of adult antisocial behavior, as well as explications of the Behavioral Inhibition System (BIS) within Gray's (e.g., 1982, 1987; Gray & McNaughton, 2000) theory of motivation. For example, numerous reviewers have concluded that electrodermal hyporeactivity (typically measured as palmar skin conductance or SC in recent years) among antisocial adults, often diagnosed as psychopaths, is a reliable finding (e.g., Arnett, 1997; Fowles, 1993; Hare, 1978; Lorber, 2004; Lykken, 1995; Scarpa & Raine, 1997; Siddle & Trasler, 1981). At least in part due to the influence of the hypothesis that poor fear conditioning creates a risk for psychopathy (e.g., Lykken, 1957, 1995), the electrodermal hyporeactivity established among antisocial adults most commonly is obtained as a reaction to anticipated aversive stimuli, such as electric shock and loud noise, or to disturbing visual images (e.g., Fowles, 1993; Fowles & Missel, 1994; Hare, 1978; Raine, 1993, pp. 218–221; Raine, Reynolds, Venables, & Mednick, 1997). In contrast, when examined during resting conditions or in response to unthreatening stimuli of moderate intensity, to which the electrodermal response (EDR) quickly habituates, the association between electrodermal hyporeactivity and antisocial behavior tends to be smaller and less reliable (Fowles, 1993; Fowles & Furuseth, 1994; Hare, 1978; Siddle, 1977). These historical conclusions have been supported in a recent meta-analysis of the association between psychophysio-

logical responses and antisocial behavior (Lorber, 2004): Among adult subjects diagnosed with psychopathy/sociopathy, the effect size for electrodermal hyporeactivity to negative stimuli was .47, whereas during resting conditions it was .29 and during tasks with nonnegative stimuli (e.g., orienting tones or affectively neutral slides) it was − .11.

The strength of the evidence linking electrodermal hyporeactivity to adult antisocial behavior, coupled with the putative link between child externalizing disorders and adult antisocial behavior, has caused some investigators to assess electrodermal hyporeactivity in children. Unfortunately, the examination of electrodermal hyporeactivity in children has been constrained by the limitations associated with administering aversive stimuli to children. As a result, research designed to assess electrodermal reactivity of children largely has used orienting stimuli of moderate intensity (e.g., Delamater & Lahey, 1983; Hinton, O'Neill, Dishman, & Webster, 1979; Schmidt, Solanto, & Bridger, 1985) to evoke the electrodermal responding. Lorber (2004) cited only two studies (Blair, 1999; Herpertz et al., 2001) that used negatively valenced stimuli in children, both outside the United States. In England, Blair (1999) showed pictures with negative content to boys ages 8 to 17 years, whereas in Germany Herpertz et al. (2001) used startle stimuli (white noise, 100 dB, 40 ms duration) with boys ages 8 to 13 years that may not be acceptable to Institutional Review Boards (IRBs) in the United States. More recently Herpertz et al. (2005) also employed pictures with negative content in boys 8–13 years old. Neither Blair (1999) nor Herpertz et al. (2005) found a selective deficit to aversive pictures. Herpertz et al. reported an overall hyporeactivity to pictures of all valences for boys with conduct disorder (CD) and with comorbid CD plus attention deficit hyperactivity disorder (ADHD). Blair found hyporeactivity to pictures portraying distress but not to those portraying threat among boys with externalizing problems and high scores on a psychopathy scale. Thus,

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pictures appear to be promising stimuli, at least for older children, but it is desirable to have additional stimuli, including those that are potentially aversive, for use with children in order to more fully map the domain of electrodermal hyporeactivity.

Two recent North American studies assessed electrodermal reactivity to extinction in efforts to understand the role of the BIS in externalizing disorders in 8–13-year-old children (Iaboni, Douglas, & Ditto, 1997) and 12–17-year-old adolescents (Beauchaine, Katkin, Strassberg, & Snarr, 2001). Although both the Iaboni et al. (1997) and Beauchaine et al. (2001) studies provided some evidence for the utility of a period of nonreward in a repetitive motor task for evoking SCRs, the failure of the Beauchaine et al. (2001) study to completely replicate the Iaboni et al. (1997) findings caused Beauchaine et al. to consider the question as to whether the extinction paradigm, in which subjects were informed that rewards would not always be delivered, was adequately frustrating to establish SCR hyporeactivity in their ADHD sample. Although Beauchaine et al. placed their question regarding the extinction task in a call for more research on disinhibited samples, the question also underscored the need for other paradigms that reliably evoke electrodermal responses from children.

A relatively large body of research in the operant conditioning literature suggests that reinforcement schedules with long inter-reinforcement intervals, as well as periods of extinction, could be used to evoke EDRs from children. That is, although research with humans often establishes the aversiveness of a stimulus through self-report ratings, or even merely common knowledge, the nonhuman instrumental conditioning literature operationalizes aversiveness through escape paradigms (e.g., Campbell, Smith, & Misanin, 1966), avoidance paradigms (e.g., Sidman, 1969), or punishment paradigms (cf. Azrin & Holz, 1966). Those research strategies have been used to establish that some schedules of reinforcement can have aversive properties—in spite of the obvious positive qualities of the reinforcers. For example, studies with several species of laboratory animals have documented that fixed-ratio (FR) schedules of reinforcement with large response requirements result in escape responding (e.g., Appel, 1963; Ferster, 1958; Thompson, 1964, 1965; Zimmerman & Ferster, 1964), with the escape from FR schedules presumed to be a product of the aversiveness of the response requirement or the low density of reinforcement. Other work established that subjects will emit an operant that avoids FR schedules of reinforcement (Gibson, 1967).

In addition to studies in which the aversiveness of a schedule of reinforcement has been established through escape or avoidance behavior, research on schedule-induced aggression can be seen as evidence of the aversiveness of some schedules of reinforcement. That is, based on the pain–aggression model (Ulrich & Azrin, 1962), theories of irritable or defensive aggression (e.g., Blanchard, 1984; Moyer, 1976), and general theories of aversively motivated aggression (e.g., Berkowitz, 1983), conditions that evoke aggressive behavior can be considered to be aversive. Because laboratory subjects who are given access to a suitable conspecific target and reinforced for a nonaggression operant on fixed-ratio schedules (e.g., Knutson, 1970), fixed-interval schedules (e.g., Richards & Rilling, 1972), rate-contingent schedules (e.g., Knutson & Kleinknecht, 1970), or behaviorally independent schedules (e.g., Flory, 1969) display target-directed attack, some investigators have interpreted the schedule-induced aggression as evidence of the aversiveness of some schedules of reinforcement (cf. Richards & Rilling, 1972).

The generality of schedule-induced aggression is reflected in data from avians (e.g., Knutson, 1970; Looney, Cohen, & Yoburn, 1976), rodents (e.g., Knutson & Schrader, 1975), primates (e.g., Hutchinson, Azrin, & Hunt, 1968), and human adults and children (e.g., Frederiksen & Peterson, 1977; Kelly & Hake, 1970; Todd, Morris, & Fenza, 1989). Taken together, the schedule-induced escape, avoidance, and aggression data suggest that schedules of reinforcement could serve as an aversive event for evoking EDRs in children.

Several lines of research related to schedule-induced aggression and other schedule-induced behaviors (e.g., pica, polydipsia) indicate that the immediate post-reinforcement period should be the point in the inter-reinforcement interval in which the schedule-induced EDRs should be identified. Theoretical and empirical analyses of various schedule-induced behaviors (termed adjunctive by Falk, 1972, or interim activity by Staddon, 1977; Staddon & Simmelhag, 1970) have established the excessive nature and noninstrumental value of the responses and, more importantly, that these schedule-induced behaviors can be distinguished from the terminal or instrumental acts that result in reinforcement. In large measure the schedule-induced behaviors occur in the post-reinforcement period, with many studies documenting a declining probability of these behaviors across time in the inter-reinforcement interval. Because the highest probability of schedule-induced behaviors (e.g., aggression) is in the immediate post-reinforcement period (Falk, 1972; Staddon & Simmelhag, 1970), because escape from a reinforcement schedule also typically occurs in the post-reinforcement period (e.g., Ferster, 1958; Thompson, 1964), and because a response requirement is not necessary for schedule-induced phenomena to occur (e.g., Flory, 1969), if schedules of reinforcement were to evoke an SCR, that evocation should occur immediately after the occurrence of reinforcement.

In summary, a large body of basic laboratory research suggests that schedules of reinforcement characterized by relatively long inter-reinforcement intervals would be aversive to children. That literature, coupled with the literature on extinction-induced SCRs (e.g., Beauchaine et al., 2001; Iaboni et al., 1997; Tranel, 1983), suggests that schedules of reinforcement with longer inter-reinforcement intervals would evoke greater SCRs and that those enhanced SCRs would be in the post-reinforcement period. Thus, it was hypothesized that children exposed to schedules of reinforcement would experience a negative emotional response to schedules of reinforcement characterized by long inter-reinforcement intervals and that the emotional response would be manifested in an SCR in the post-reinforcement period. If such a pattern were identified, it would offer another means of evoking EDRs from children for testing theoretical formulations in which the EDR plays a central role. Thus, the present study was designed to determine whether SCRs would be differentially evoked by different schedules of reinforcement.

EXPERIMENT 1

Method

Participants

Participants were recruited from a pool of children whose parents had previously indicated a willingness to approve participation in psychological research at The University of Iowa. Parents received a phone call describing the research and inviting children to participate. Children between the ages of 8 and 10 years were

eligible to participate. A total of 20 participants were recruited but data were only obtained from 16 participants due to equipment malfunctions. Participants providing data had a mean age of 9.2 years, 8 (50%) were boys, 15 were Caucasian, and all but 1 were right-handed.

Equipment

To record SC, silver–silver chloride electrodes filled with Johnson & Johnson KY jelly electrolyte (Edelberg, 1967) were attached to the distal phalanges of the first and second digits of the non-dominant hand with double-sided, adhesive electrode collars defining a skin contact area for the electrode jelly with a diameter equal to 8.0 mm (calculated area of contract $= 0.50$ cm^2) and secured with 3M micropore tape wrapped around the phalange. Consistent with recommendations by Fowles et al. (1981), SC was recorded by applying a constant 1.0 V (DC) (stepped down from a 1.5-V flashlight battery) across the silver–silver chloride electrodes. The voltage drop measured across a 1-KΩ series resistor is proportional to the conductivity of the child's skin. This voltage was amplified by a Coulbourn S75–07 direct-coupled bioamplifier, passed through a 2-Hz low-pass filter to attenuate high frequency noise (Edelberg, 1967), and digitized at a frequency of 25/s by a Metrabyte DAS-16 analog-to-digital (A-D) board installed in a personal computer. A Wheatstone Bridge incorporating the series resistor allowed balancing or canceling a portion of the DC signal if it exceeded the 20-μS full-scale range established for the Metrabyte A-D board. The output of the Wheatstone bridge also went to a second S75-07 DC bioamplifier via a resistance–capacitance (R-C) coupler that filters standing voltages, allowing greater amplification (and thus sensitivity of measurement) of electrodermal responses (i.e., a 5-μS full-scale range for the A-D board).

A computer-controlled task implementing varying schedules of reinforcement required the child to press any key on a standard alphanumeric keyboard when a letter appeared on a computer CRT. When reinforcement occurred, the child received a 25-cent coin delivered by a solenoid-operated coin dispenser located adjacent to the computer CRT. A cumulative counter located in the middle of the bottom portion of the CRT maintained an updated record of the child's total rewards. A response was defined as pressing any key on the keyboard at least once while a given character was displayed on the CRT, with the characters presented at a constant rate of one character every 2 s regardless of the schedule of reinforcement being used. Additional key presses during the 2-s period had no effect.

Schedules of Reinforcement

Although schedule-induced phenomena are more a function of inter-reinforcement intervals than response requirements (see Flory, 1969; Staddon, 1977), a response requirement was included to assure the children attended to the task and the contingencies throughout the session. In operant conditioning nomenclature, Signaled Conjunctive FRnFI2 schedules of reinforcement were used. For each reinforcer presented, the child had to complete a fixed-ratio (FR) requirement applied to a fixed-interval (FI) schedule of 2 s. Thus, in an FR10FI2 the child had to strike a key at least once when the character was presented every 2 s, and they had to complete 10 of those FI2 responses for a reinforcing coin to be presented. Should the child fail to respond during the 2-s stimulus presentation, that stimulus was not counted toward the FR requirement. However, in almost all cases the children responded to all stimuli. By controlling re-

sponse rate with the signaled FI component of the schedule and the reinforcement rate with the FR schedule, the inter-reinforcement intervals within schedules and the responses per reinforcement were virtually identical across subjects. Moreover, as evidenced by steady responding, all children stayed on task throughout the session.

Two schedules of reinforcement were used. An FR10FI2 provided reinforcement at a relatively high rate, with approximately 20 s between reinforcers. An FR30FI2 required three times the number of responses and resulted in approximately 60 s between reinforcer delivery. In addition to these two reinforcement schedules, based on the extinction-induced aggression findings (e.g., Azrin, Hutchinson, & Hake, 1966; Knutson, 1970), the subjects were exposed to periods of extinction (EXT) during which characters were presented at a 2-s rate, but no reinforcement was delivered, regardless of subject responding. The EXT periods lasted 90 s. The two schedules of reinforcement and the periods of extinction were identified by both the color and position of the characters presented on the computer screen. All children experienced 23 reinforcements delivered on the FR10FI2 schedule, 13 reinforcements delivered on the FR30FI2, and four 90-s periods of EXT. The sequence of reinforcement schedules and the EXT components is shown in Table 1.

Table 1. *Experiment 1 Reinforcement Schedules*

Schedule
FR10FI2
FR10FI2
FR10FI2
FR10FI2
EXT
FR10FI2
FR10FI2
FR10FI2
FR10FI2
FR30FI2
FR30FI2
FR30FI2
FR30FI2
FR30FI2
EXT
FR10FI2
FR10FI2
FR10FI2
FR10FI2
FR10FI2
FR10FI2
EXT
FR30FI2
FR30FI2
FR30FI2
FR30FI2
FR10FI2
FR10FI2
FR10FI2
FR10FI2
FR30FI2
FR30FI2
FR30FI2
FR30FI2
FR10FI2
FR10FI2
FR10FI2
FR10FI2
EXT
FR10FI2

Procedure

Informed consent was obtained from a parent of all participants. In addition, all participants provided their assent prior to beginning the task. Participants were then escorted to the laboratory and were asked to wash (with Ivory Soap) and dry their hands. They were then seated in a comfortable chair. Electrodes were attached to the distal phalanges of the first and second digits of the nondominant hand, followed by a 10-min period to promote hydration of the skin. The first 5 min consisted of testing the intercom system, testing the electrodermal recording equipment by having the participant take a quick, deep breath, and answering any questions that the participant may have had about the task. The second 5 min of the hydration period served as a rest period during which baseline electrodermal activity was recorded. Following the 10-min hydration period, the participant was asked to move to the computer desk where the procedure was explained and the participant was able to practice the task. The experimenter demonstrated one schedule with an FR5FI2 requirement, and then had the participant practice two of the FR5FI2 schedules prior to beginning the task. Following the assurance that the participant understood the procedure, the experimenter left the room and the task began. All sessions were video-recorded to ensure consistency across participants as well as to visually monitor the participant without being present in the room. The actual task required approximately 40 min and all participants received a total of $10 in 25-cent reinforcers.

Quantification/Reduction of Electrodermal Data

The amplitude of schedule-induced SCRs associated with each reward was calculated by subtracting the minimum skin conductance value during seconds 0–2 from the maximum value during seconds 2–5 following the reward (Dawson, Schell, & Filion, 2000), using the R-C coupled channel. In addition, to determine whether reactions to extinction varied across the time in extinction, as would be predicted from the extinction-induced aggression literature, we had planned to divide each of the 90-s extinction periods into three 30-s segments and count nonspecific SCRs. However, observations during data collection indicated that SCRs during the extinction periods were rare (in spite of the motor activity of depressing computer keys), suggesting that no differences would be found across these segments. As a check on these observations, the variance of the SCR channel during these periods was assessed as an easily computed, crude estimate of nonspecific responding.

Results

As noted, the original plan of analysis was to assess the SCR following the reinforcer presentations for the two schedules of reinforcement and to assess changes in nonspecific SCRs across the three EXT segments as indicated by SC variance. However, the SC variance across the three 30-s segment EXT components showed no systematic change. Similarly, there was no systematic difference in SC variance within EXT segments as a function of the preceding schedule of reinforcement. Importantly, although postsession interviews indicated the children recognized the changing colors of characters on the screen, the children did not associate the EXT color with an absence of reinforcement. For that reason, the structure of the analysis was altered to treat the period of EXT as a 90-s addition to the inter-reinforcement interval for the next reinforcer presentation. Thus, the SCR response to EXT was actually the SCR response to the first

reinforcer presentation following EXT. When EXT preceded an FR10FI2, the interval from the preceding reinforcer was approximately (90+20 =) 110 s and when the EXT preceded an FR30FI2, the inter-reinforcement interval was approximately (90+60 =) 150 s. For analysis, these four post-reinforcement SCRs that followed EXT were combined regardless of the schedule that controlled the reinforcer, and those SCRs were excluded from the analyses of the FR10FI2 and FR30FI2 schedules.

Figure 1 shows the mean SCR following reinforcer presentation according to the two schedules of reinforcement and the first reinforcer following EXT. A mixed ANOVA of the mean SCR scores was conducted with Schedule as the within-subject factor and subject Sex as the between-subjects factor. As expected, the Sex $\times$ Schedule interaction, $F(1,14) = 0.081$, and the main effect of Sex, $F(1,14) = 0.001$, did not approach statistical significance.

The apparent differences in SCR among schedules of reinforcement depicted in Figure 1 were statistically significant after the Greenhouse–Geisser correction to the significance level, $F(2,30) = 15.35$, $p < .001$, partial $\varepsilon^2 = .51$. An examination of pairwise comparisons was then completed applying Bonferroni alpha corrections to guard against Type I errors. The mean amplitude of SCRs in response to rewards following the FR30FI2 schedule was significantly larger than those following the FR10FI2 schedule, $p < .05$, and the mean SCRs to reinforcers following the EXT schedule were significantly larger than both those following the FR10FI2 schedule, $p < .001$, and those following the FR30FI2 schedules, $p < .05$. A post hoc trend test indicated that differences in mean SCR across the schedules shown in Figure 1 followed a linear trend, $F(1,15) = 22.98$, $p < .001$, partial $\varepsilon^2 = .61$.

Figure 2 shows the mean SCR following each reinforcer presentation. The apparent lack of habituation during the first two blocks of the FR30FI2 schedule was of interest—because lack of habituation is rare for SC—and was examined in two ways. First, within-subject trend analyses were conducted for trials within each schedule—that is, for the five trials of the first FR30FI2 series, for the three trials of the second FR30FI2 series, and the four trials of the third FR30FI2 series. Similar analyses were conducted for the FR10FI2 schedules for comparison. Second, a within-subject trend analysis was conducted for all 12 FR30FI2 trials without regard to intervening schedules in order to quantify the pattern of delayed habituation, and a similar analysis was conducted for the 20 FR10FI2 trials for comparison. None of the trends for the first set of analyses (including those for the FR10FI2 schedules) were significantly different from zero. Similarly, the trend analyses across all trials were not
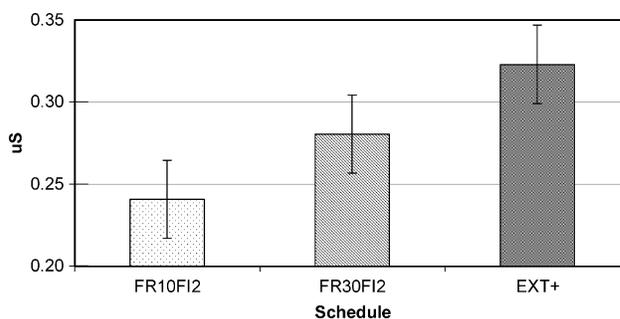

Figure 1. Mean electrodermal response following reinforcement presentation for each schedule of reinforcement in Experiment 1.
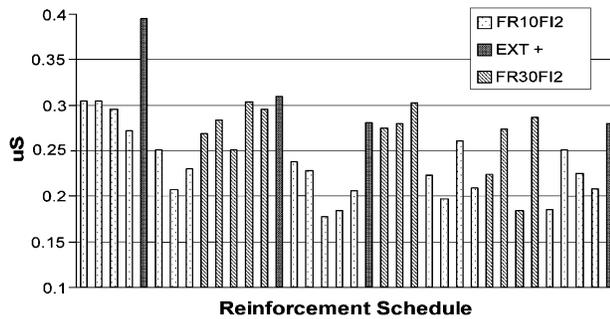
Figure 2. Mean electrodermal response following each successive reinforcement presentation for each schedule of reinforcement in Experiment 1.

significant. Thus, there was no evidence of habituation either within blocks or across all blocks for either schedule.

Discussion

In general, the results of Experiment 1 provided evidence that children will display a greater amplitude SCR in response to the presentation of a reinforcer when that reinforcer is controlled by a schedule of reinforcement that results in longer inter-reinforcement intervals. The findings are congruent with the existing work on schedule-induced adjunctive behavior (Falk, 1972; Staddon, 1977) and the hypothesis that schedules of reinforcement have aversive properties (Richards & Rilling, 1972). The findings are not unambiguous, however. Based on several lines of evidence, exposure to a period of EXT following a history of reinforcement for an operant would be expected to evoke an aversive reaction, and that reaction should be a function of time in the period of EXT (see Azrin et al., 1966; Knutson, 1970). That is, reactions early in extinction should be greater than reactions later in extinction. Such a pattern was not evidenced in the SCR data. Importantly, however, it is possible that the structure of the sessions did not provide a sufficient level of experience and reinforcer exposure to evoke the extinction-induced reaction. Moreover, interviews with the children indicated that, although they recognized that the characters changed colors on the computer monitor, they could not verbalize the specific schedules to which they were exposed, including EXT. Thus, treating EXT as being combined with the next reinforcement schedule was probably appropriate.

Although overall the data were consistent with the hypothesis that longer inter-reinforcement intervals would be associated with larger SCRs, an inspection of the SCR data on a reinforcer by reinforcer level (see Figure 2) indicated that the mean SCR in response to the reinforcer presented in the schedule of reinforcement following the first EXT schedule was much greater than any other SCR. When the overall ANOVA was conducted with the first postextinction response omitted, the repeated-measures ANOVA remained statistically significant after the Greenhouse–Geisser correction, $F(2,30) = 7.80$, $p < .01$, partial $\varepsilon^2 = .34$. However, the pairwise comparison between the mean SCR to the FR30FI2 schedule and the reinforcers following EXT was no longer significant, $p = .71$. Thus, although the findings are consistent with the notion that the post-reinforcement period in schedules of reinforcement associated with longer inter-reinforcement intervals should evoke greater electrodermal reactions, the results are not unambiguous.

EXPERIMENT 2

Experiment 2 was conducted to resolve the ambiguity in the data of Experiment 1. That is, Experiment 2 was designed to determine whether the SCR evoked in the post-reinforcement period in Experiment 1 was systematically related to the length of the inter-reinforcement interval or whether it was an acute response to the long period without reinforcement associated with the first exposure to the extinction component. To make that determination, an additional schedule of reinforcement was included, extinction was eliminated, and the schedules were arranged to approximately equate the number of exposures to the individual schedules and to assure an equal number of transitions between reinforcement schedules. Finally, the experiment was designed to increase the generality of the findings by recruiting a more diverse sample of children.

Method

Participants
Twenty-seven children between the ages of 8 and 12 provided data for the experiment, with 15 children recruited from the same University of Iowa pool as Experiment 1. A second sample of 12 children was recruited from an economically disadvantaged sample who had been enrolled in an ongoing study of parenting and social development. Parents of these disadvantaged children received a letter describing the research followed by a phone call inviting children to participate. The participants recruited through the same procedure as Experiment 1 had a mean age of 9.42 years and were 46.7% male; all but 1 were Caucasian and all but one were right-handed. The economically disadvantaged participants had a mean age of 9.36 years; 75% were boys, 50% were members of ethnic minority groups, and 75% were right-handed.

Equipment and Procedures
The same equipment used in Experiment 1 was employed in Experiment 2. Except for the changes in the schedule of reinforcement, all procedures were identical to those in Experiment 1.

Schedules of Reinforcement
As in Experiment 1, children were reinforced for responding with 25-cent coins. In addition to the FR10FI2 and FR30FI2 schedules used in Experiment 1, an FR50FI2 component was included. The inter-reinforcement interval associated with the FR50FI2 schedule was approximately 100 s and slightly less than the combined time for the FR10FI2 and EXT used in Experiment 1. Each of the schedules was identified by the color and position of the letters presented on the computer monitor. The FR10FI2 schedule was signified with red letters on the left-hand side of the screen; the FR30FI2 schedule was signified with blue letters on the right-hand side of the screen; and the FR50FI2 schedule was signified with green letters in the middle of the screen. Characters that cued responding were presented at the rate of one character every 2 s. To complete the entire session within an hour, the FR10FI2 schedule was presented 14 times, the FR30FI2 schedule was presented 11 times, and the FR50FI2 schedule occurred 11 times. The sequence of the schedules was arranged so that there were two transitions between different schedules of reinforcement except for the transition from the FR30FI2 to the FR10FI2 schedule, in which there was only one transition. This
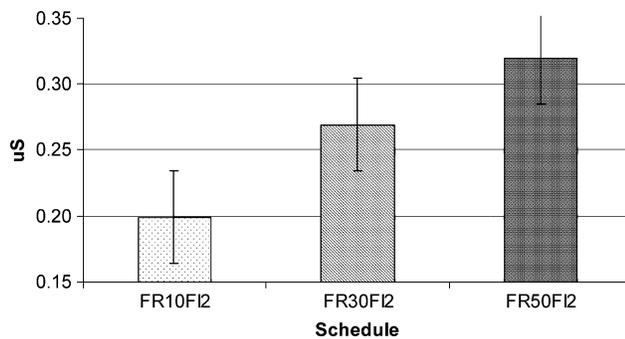
Figure 3. Mean electrodermal response following reinforcement presentation for each schedule of reinforcement in Experiment 2.

Figure 4. Mean electrodermal response following each successive reinforcement presentation for each schedule of reinforcement in Experiment 2.

compromise was necessary to fit the schedules into the forty 25-cent reinforcer ($10) framework and to complete the protocol within an hour. Each participant received a total of $10 from the programmed reinforcement schedules and the practice trials. Table 2 provides a listing of the sequence of the schedules of reinforcement presented to each subject.

Quantification/Reduction of Electrodermal Data

Electrodermal responses to each reinforcer presentation in Experiment 2 were calculated in the same manner as in Experiment 1.

Results

Figure 3 shows the mean SCR following reinforcer presentation for each of the three reinforcement schedules. The data were analyzed using a mixed repeated-measures ANOVA with Subject Source (university pool or disadvantaged sample) as one between-subjects factor, Sex of subjects as the second between-subjects factor, and Schedule of reinforcement as the within-subject factor. Neither the three-way Schedule × Subject Source × Sex interaction, $F(2,46) = 0.37$, the two-way Sex × Schedule interaction, $F(2,46) = 0.42$, the two-way Subject Source × Sex, $F(1,23) = 0.44$, interaction, nor the two-way Subject Source × Schedule interaction, $F(2,50) = 0.48$, approached statistical significance. Similarly, the main effects of Sex, $F(1,23) = 0.13$, and Subject Source, $F(1,25) = 0.39$, did not approach statistical significance. As hypothesized, the amplitude differences in SCR in response to different schedules of reinforcement depicted in Figure 3 were statistically significant after adjusting the significance level with the Greenhouse–Geisser correction, $F(2,50) = 12.93$, $p < .001$, partial $\varepsilon^2 = 0.34$. An examination of pairwise comparisons applying Bonferroni corrections to reduce risk of Type I error indicated that the magnitudes of SCRs in response to rewards following the FR30FI2 schedule were significantly larger than those following the FR10FI2 schedule, $p < .01$, the SCRs following the FR50FI2 schedule were significantly larger than both those following the FR10FI2 schedule, $p < .01$, and the FR30FI2 schedules, $p < .05$. Furthermore, consistent with Experiment 1, a significant linear trend, $F(1,25) = 14.13$, $p < .001$, partial $\varepsilon^2 = 0.36$, in SCR magnitude as a function of schedule of reinforcement was identified.

Because the data of Experiment 1 suggested that the SCR in response to a long inter-reinforcement interval might be an acute consequence of an initial exposure, the mean SCR responses to
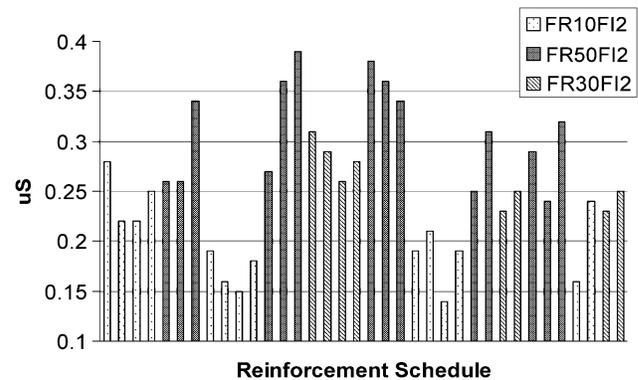
each successive reinforcer presentation were plotted in Figure 4. The figure provides a clear indication that, although there was variability among reinforcers within schedules and a degree of attenuation of responding with successive exposures to the same schedule, the differences in schedule-induced SCR as a function of the schedule of reinforcement is readily apparent. Thus, the overall mean differences are not a function of an acute initial exposure.

As before, trend analyses were used to examine both the trials within blocks for each schedule and the trails for a given schedule across all blocks. No within-block trends were significant except for the increase for the two trials in the third FR50 block, $F(1,26) = 6.69$, $p < .016$, which is not of theoretical significance. All three of the analyses across all trials yielded significant findings: a quadratic trend for the FR10FI2 schedule, $F(1,26) = 9.89$, $p < .004$, and cubic trends for the FR30FI2, $F(1,26) = 5.45$, $p < .028$, and FR50FI2, $F(1,26) = 4.40$, $p < .046$, schedules. The quadratic trend for FR10FI2 reflects the initial decline in amplitude followed by a slight increase. In contrast, the cubic trends for the other two schedules reflect an initial increase followed by a decline and then flattening. Thus, there was a tendency for an increased amplitude of SCR over the early trials for the FR30FI2 and FR50FI2 schedules.

Discussion

The results of the second study replicate and extend those obtained in Study 1, showing a clear effect of the length of the inter-reinforcement interval on SCR amplitudes across three intervals of approximately 20, 60, and 100 s. Thus, the effects of longer inter-reinforcement intervals in the first study cannot be attributed to an effect limited to the novelty of the longer interval associated with the first extinction period. These overall effects of inter-reinforcement intervals are consistent with the schedule-induced phenomena established with nonhuman subjects (e.g., Falk, 1972; Staddon, 1977). Moreover, the overall schedule differences, as well as the trend analyses and the variability in responses among reinforcers within schedules, are consistent with the patterns of data in the schedule-induced aggression literature reviewed in the introduction. Thus, the results of Study 2 are theoretically consistent with the hypothesized link between schedules of reinforcement with long inter-reinforcement intervals and the induction of an emotional state. Further, because

Table 2. *Experiment 2 Reinforcement Schedules*

Schedule
FR10FI2
FR10FI2
FR10FI2
FR10FI2
FR30FI2
FR30FI2
FR30FI2
FR10FI2
FR10FI2
FR10FI2
FR10FI2
FR50FI2
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these results were derived from a larger, more socioeconomically diverse sample of participants, the generalizability of the findings would seem to be enhanced.

General Discussion

The results of the two experiments provide evidence of schedule-induced SCRs in which larger SCRs are associated with longer inter-reinforcement intervals. At least descriptively, there is a tendency for habituation to be delayed for the longer inter-reinforcement intervals (FR30FI2 and FR50FI2), indicating that the presentation of monetary incentives in this scheduled reinforcement context effectively elicits SCRs. Our preferred interpretation of these results at least partially attributes the larger SCRs with increasing intervals to the aversiveness of reinforcements signaling long periods without reinforcements. That preference reflects the large animal literature reviewed in the introduction documenting the aversiveness of such schedules of reinforcement and the parallels between these data and the schedule-induced phenomena reviewed above. If this interpretation is valid, this paradigm provides an effective method for eliciting responses to aversive stimuli in children that is fully acceptable to the children, their parents, and IRB reviewers and that should facilitate testing hypotheses regarding selective fear deficits in antisocial children and adolescents.

Nevertheless, because larger responses tend to be associated with longer ISIs (e.g., Siddle, Stephenson, & Spinks, 1983), there is a confounding of the effects of ISI per se and of the prediction that longer inter-reinforcement intervals are more aversive and should elicit larger responses—that is, an important alternative interpretation views the quarters as purely appetitive stimuli and attributes the results simply to longer ISIs. In their review of habituation, Siddle et al. (1983) concluded that relatively long ISIs produce larger electrodermal responses and a slower rate of response decrement. The larger responses with longer ISIs is a reliable effect, having been reported for a wide range of stimuli—for example, low intensity tones or white noise (Gatchel & Lang, 1974; Geer, 1966), mild shock and (pleasant) cool air puffs in a hot room (Furedy & Scull, 1971), loud white noise of 90-dBA intensity (Baltissen, 1993), and clearly aversive white noise of 110 dB (Baltissen & Boucsein, 1986) or 120 dB (Raskin, Kotses, & Bever, 1969) intensity. Thus, the increasing amplitude of the mean responses to the different schedules almost certainly reflects to some extent the effects of longer ISIs, and it is not possible from the present experiments to know for certain whether increased aversiveness contributes to this effect.

Increases across trials or even delayed habituation could be helpful in supporting the aversiveness of the stimuli, inasmuch as both are indications of a defensive response (DR; Boucsein, 1992, pp. 225–226). Consequently, the effects of repetition of the schedules within blocks should be considered. The SCR shows habituation to almost all stimuli (e.g., Graham, 1973, p. 169). In theory, the SCR to stimuli that are aversive enough to elicit a DR should not show habituation—in contrast to the habituation expected for the orienting response (OR) to novel and significant stimuli. However, Boucsein (1992, p. 226) concluded that the nonhabituation of the SCR DR has not been established. He cites Boucsein, Baltissen, and Euler (1984) and Baltissen and Boucsein (1986) as reporting clear sensitization (i.e., increased amplitude over trials) of the SCR to 110-dB white noise, but he also notes that Turpin and Siddle (1979) found only an initial delay of habituation to 105-dB white noise. Although not cited by Boucsein in this context, Raskin et al. (1969) observed delayed habituation to 120-dB white noise. Boucsein (p. 226) concludes that, rather than expecting a distinction between habituating OR and nonhabituating DR reactions, one should expect a quantitative difference in the course of habituation between the OR and the DR. From this perspective, the apparent delayed habituation observed for the first two blocks of FR30FI2 in Experiment 1 and for all but the second blocks for FR30FI2 and FR50FI2 in Experiment 2 is suggestive of the delayed habituation characteristic of the DR, which would imply aversiveness.

The above argument must be evaluated in the context of the effects of very long ISIs on habituation. As noted above, Siddle et al. (1983) concluded that habituation decreases with increasing ISIs. Specifically, those authors cite Schaub (1965) and Germana (1968; incorrectly cited as 1969) as showing little or no habituation with ISIs of 120 and 240 s. Schaub employed a 64-dB white noise stimulus and a between-subjects design with fixed ISIs of 30, 60, and 180 s with 5 Ss per cell. Descriptively, the response amplitude increased over trials through trial 10 and then began to decline for the 180-s ISI, was variable but with little systematic trend for 60-s ISI, and showed a modest decline for 60-s ISI. There was a significant main effect of ISI, but the ISI × Trials interaction, $F(18,108) = 2.12$, p < .05, would not survive a

Greenhouse–Geisser reduction of *df* to 2 and 12, and there was no test of the significance of the increase over trials for the 180-s ISI group. In a second experiment, Schaub reported mean response amplitudes across six trials with the second trial slightly lower than the first for a 120-s ISI (interspersed with shorter ISIs) and a decline thereafter—that is, there was no evidence of increased amplitudes over trials. Thus, at a descriptive level, there were increases over trials for the 180-s ISI, habituation delayed by one trial for the 120-s ISI, and a modest decline for the 60-s ISI, albeit without statistical significance.

Germana (1968) presented the same 10-digit number for 5 s for four trials followed by a different 10-digit number on the fifth trial (with instructions to attend to the stimuli) to eight ISI groups (5, 15, 30, 45, 60, 90, 120, and 240 s) with eight Ss per cell. A Groups $\times$ Trials ANOVA for Trials 1–4 yielded a main effect of ISI but neither a Trials main effect nor an interaction of Trials $\times$ ISI (both $Fs < 1$). Thus, although there appeared to be only a small decline over trials for the 120- and 240-s groups compared with larger declines for the shorter ISIs, the inference of lesser habituation was not supported by a significant interaction effect. (Possibly the failure of significance can be attributed to difficulty of demonstrating an interaction effect for a graded response with an 8 ISIs $\times$ 4 Trials design.) Descriptively, for the 240-s ISI the response amplitude was identical for Trials 1 and 2 and then declined slightly on each of Trials 3 and 4. For the 120-s ISI there was a small decline from Trial 1 to Trial 2 with very little change thereafter. That is, even descriptively there was not an increase over trials at very long ISIs.

Other investigators have reported response decrements over the first few trials even with relatively long ISIs. Using 90-dB tones, Baltissen (1993) presented figures showing clear SCR habituation for 70-s ISIs (often alternating with 10-s ISIs) and delayed habituation for 140-s ISIs (alternating with 20-s ISIs). In Winokur, Stewart, Stern, and Pfeiffer (1962) mixed ISIs of 30, 60, and 90 s yielded declines over the first five trials without interruption for shock and with only one small reversal for a 60-dB tone. ISIs as long as 100 s with a 65-dB tone produced apparent rapid habituation for Gatchel and Lang (1974), although the reporting of data as moving averages of three trials may have obscured changes over the first three trials. Similarly, an average ISI of 105 s (range 95–115 s) with 65-dB tones yielded a sharp decline from Trials 1–4 to Trials 5–8, but trends over the first four trials were hidden by reporting the data in blocks of four trials. It should also be noted that Baltissen and Boucsein's (1986) increases over trials involved both a highly aversive 110-dB stimulus and a relatively long average ISI of 75 s (range 60–90 s).

Overall, these results suggest that declines in SCR amplitude over the first few trials are seen with ISIs up to an interval between 105 and 120 s unless the stimuli are very intense. Either delayed or no habituation may be seen at ISIs of 120 s. Even at 180 s the only descriptive finding of an increase over trials to a nonaversive stimulus was based on a small sample of 5 subjects per condition. Thus, the delayed habituation for ISIs of approximately 60 s (FR30FI2) in the present studies is unusual and might reflect greater aversiveness. The delayed habituation for ISIs of approximately 100 s (FR50FI2) is not as clearly unusual, inasmuch as the ISI is close to the 120 s cited above for delayed or absent habituation. Of course, if the FR30FI2 schedule is aversive due to delayed reinforcement, by inference the same would be true of the FR50FI2 schedule.

Even if the sustained responding to the reinforcement schedules is entirely attributable to appetitive and ISI effects, the ability to elicit SCRs in children as young as age 7 is likely to be of use in the context of antisocial behavior. Although a presumed selective deficit in SCRs to aversive stimuli has long been assumed for people with psychopathy, there have been strong suggestions of SCR hyporeactivity among a broader group of chronically antisocial individuals (Raine, 1993, pp. 218–221; 1997), such as the findings cited above for Herpertz et al. (2005). Over the past 15 years Patrick and his colleagues (e.g., Benning, Patrick, Blonigen, Hicks, & Iacono, 2005; Benning, Patrick, Hicks, Blonigen, & Krueger, 2003; Benning, Patrick, & Iacono, 2005; Patrick, 2007; Patrick, Bradley, & Lang, 1993; Patrick, Cuthbert, & Lang, 1994; Patrick, Hicks, Krueger, & Lang, 2005; Patrick & Lang, 1999) have shown substantial differences for the personality and psychophysiological correlates of the two major factors or dimensions that are found both in the Psychopathy Checklist-Revised (Hare, 1991, 1998, 2003; Hare et al., 1990; Harpur, Hare, & Hakstian, 1989) that is used to diagnose psychopathy among incarcerated felons and in the Psychopathic Personality Inventory (PPI; Lilienfeld & Andrews, 1996), a self-report instrument for use with normal populations.

Clarification of this issue has recently been provided by Benning, Patrick, and Iacono (2005), who found *both* a selective fear deficit and an overall hyporeactivity associated with the factors or personality dimensions related to psychopathy. Factor 1, said to include the affective–interpersonal or core features of psychopathy, reflects the traditional view of psychopathy and is associated with a selective fear deficit as assessed via affective modulation of the startle response. Factor 2, said to reflect impulsive, chronic antisocial behavior, is related to a broad spectrum of externalizing disorders (e.g., Blonigen, Hicks, Krueger, Patrick, & Iacono, 2005; Burt, Krueger, McGue, & Iacono, 2001; Iacono, Carlson, Malone, & McGue, 2002; Iacono, Carlson, Taylor, Elkins, & McGue, 1999; Krueger et al., 2002) that includes the comorbid Attention Deficit Disorder/Conduct Disorder pathway to psychopathy (Fowles & Dindo, 2006). Using the PPI in a community sample, Benning, Patrick, and Iacono (2005) found that Factor 1 correlates with reduced SCRs selectively to aversive pictures, whereas Factor 2 correlates with reduced SCRs to the entire range of positive, neutral, and negative stimuli. Thus, procedures that reliably elicit appetitive responses in children would be valuable in assessing this second, Factor 2 deficit that apparently is much more common among antisocial children than is the Factor 1 low fear deficit.

In short, although the present findings are consistent with the theoretical formulation that schedules of reinforcement can have aversive properties that are primarily in the post-reinforcement period, the existing evidence on ISI influences on SCR makes reaching an unequivocal conclusion impossible. Methodologically, however, the present findings offer a laboratory paradigm that reliably evokes SCR in children. Thus, the paradigm offers considerable promise as a means of testing hypotheses regarding individual differences in SCR in research on temperament and behavior disorders. Specifically, when considered in the context of the inconsistent findings of the Beauchaine et al. (2001) and Iaboni et al. (1997) studies that were based on attempts to use extinction-induced SCRs, the present findings suggest that schedule-induced SCRs might help address the Beauchaine et al. question regarding the use of frustrative nonreward in studies of externalizing disorders of children.

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