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A startle-probe methodology for investigating the effects of active avoidance on negative emotional reactivity

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Abstract

This study introduces a new methodology for investigating the impact of active avoidance and behavioral control on defensive emotional reactivity using the startle reflex. A between-groups yoked design was devised that permitted manipulation of participants' perception of control over an aversive event (loud noise) while precisely controlling motor activity and noxious stimulation. Startle responses to tactile (airpuff) probes were compared during threat/performance trials and neutral trials. Results conclusively demonstrated cross-modal startle potentiation in the context of a continuous motor performance task. Also, consistent with prior research, heart rate increased with perceived control. However, behavioral control per se did not appear to mitigate defensive emotion as indexed by startle potentiation. These findings indicate that other parameters may mediate the efficacy of active coping in addition to control, and that the startle probe paradigm can provide a valuable tool for investigating these parameters in future research. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

An extensive literature exists on the psychological and physiological consequences of alternative strategies for coping with stressful events. This study introduces a novel, startle-probe methodology for investigating changes in defensive

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emotional reactivity during coping. The startle response is a reflexive reaction to a sudden probe stimulus (e.g. a noise burst). Of particular relevance to the study of stress and coping is the finding that the magnitude of the human startle blink response increases reliably during processing of aversive cues, and that this effect (known as fear-potentiated startle; Davis, 1986) is diminished by manipulations that attenuate negative emotional reactivity (e.g. Patrick et al., 1996).

1.1. Potentiated startle as an index of negative emotion

Acoustic startle potentiation has been observed in humans during anticipation of shock (Grillon et al., 1991, 1993; Hamm et al., 1993), viewing of unpleasant slides (Vrana et al., 1988), and imagery of fearful situations (Vrana and Lang, 1990; Cook et al., 1991), and degree of startle potentiation has been shown to covary with individual differences in negative emotional reactivity (e.g. Cook et al., 1992; Patrick, 1994). Lang et al. (1990) postulated that startle reactivity is modified by emotional state as a function of response matching: During exposure to an unpleasant foreground (e.g. shock warning cue or aversive slide) that elicits a defensive state, the protective startle reflex is augmented. Conversely, when the coincident motivational state is positive (appetitive), a mismatch occurs and the protective startle reaction is diminished. In this sense, startle response modulation provides a direct index of the valence (appetitive/defensive) component of emotional reactivity. Based on neuroanatomical research, Davis (1986) concluded that startle reflex potentiation in animals is mediated by the amygdala—a key component of the subcortical defensive motivational system (Lang, 1995; LeDoux, 1995).

1.2. Active avoidance and stress

An issue of central importance in the study of fear and negative emotionality is the question of what situational and dispositional variables might operate to mitigate stress reactivity. In this regard, it has been suggested that active coping can alter the response to stress at a fundamental motivational level. Reviewing the animal learning literature, Gray (1987) theorized that behavior involving active attempts to evade or terminate a noxious stimulus (active avoidance) is mediated by the appetitive motivational system, whereas behavioral inhibition in the face of punishment cues (passive avoidance) is mediated by the aversive system. Human psychophysiological research has shown that, vis-a-vis response patterns during passive endurance of a stressor, active avoidance is associated with increases in heart rate (HR) level, heightened ratings of control, and in some studies diminished electrodermal activity (EDA) and self-reported anxiety (Obrist, 1976; Szpiler and Epstein, 1976; Light and Obrist, 1980; Lovallo et al., 1985; Sosnowski et al., 1991). In an integrative review, Fowles (1980, 1983) postulated that the characteristic HR acceleration observed during active coping reflects the mobilization of the human equivalent of Gray's appetitive ('behavioral activation') system. These lines of work thus converge on the thesis that active avoidance behavior is regulated by a system that works in opposition to the defensive motivational system, and which accordingly mitigates the response to an anticipated stressor.

Autonomic response measures are inarguably useful and informative, but they are complex and indirect indices of motivational state. EDA is not a measure of negative emotional reactivity per se: Rather, it is a nonspecific index of sympathetic *arousal* that increases during either pleasant or unpleasant stimulation (Greenwald et al., 1989). A similar point can be made with regard to HR, which is also subject to sympathetic influence (Obrist, 1981). Furthermore, HR response is influenced greatly by the metabolic and processing demands of a task, so that the response to an aversive stimulus can be either acceleratory or deceleratory depending on the context of exposure (Obrist, 1981; Obrist and Light, 1988; Lang et al., 1990; Vrana and Lang, 1990). Consequently, studies employing HR and EDA as indices of negative emotion permit only tentative conclusions concerning the impact of active avoidance on defensive reactivity.

Our understanding of the effects of coping behavior on affective response, and the pertinent parameters and mechanisms of its effects, could benefit greatly from the use of a sensitive and direct index of defensive response mobilization. Startle reflex potentiation appears to provide such a measure. During an emotion-evoking visual foreground, a change in the startle response to an intervening, different-modality probe can provide information about the *valence* of the ongoing affective state (appetitive or defensive; Lang et al., 1990): In contrast with HR or EDA, reflex potentiation directly implies a defensive orientation. If active efforts to cope with an anticipated stressor mitigate defensive reactivity, then startle potentiation should be smaller than during passive anticipation of the same noxious event. In this paper, we introduce a startle-probe methodology for investigating changes in emotional state associated with active avoidance of a stressor.

1.3. Startle potentiation and active/passive response sets

Patrick and Berthot (1995) examined the impact of an active response set on emotional reactivity using the startle reflex measure. Participants in this study either passively awaited, or prepared to escape, an anticipated noxious noise blast. A warning cue preceded each noise blast, and physiological activity, including blink responses to acoustic startle probes, was recorded during the warning interval and during periods between warning cue trials. *Active* participants were able to terminate the noise blast immediately with a switch press. Yoked *passive* participants received equivalent noise exposures with no control over stimulus duration. In this paradigm, which involved anticipation and response preparation rather than execution of an avoidance response, active participants showed greater HR deceleration late in the warning interval than passive participants (cf. Lacey and Lacey, 1970; Lang et al., 1978). However, the primary hypothesis that an active response set would attenuate defensive emotional reactivity was not supported: Active participants showed the same degree of startle potentiation during warning intervals as passive participants.

In their report, Patrick and Berthot (1995) acknowledged that the task manipulation involved preparation for an escape response rather than overt active avoidance. As noted, response preparation in this case led to cardiac deceleration, with no accompanying change in startle reflex potentiation. Psychophysiological research on coping has more typically examined autonomic changes during *execution* of an avoidance response, and it has been argued that cardiac acceleration during active coping reflects mobilization of the appetitive behavioral activation system (Fowles, 1980). Accordingly, Patrick and Berthot suggested that a stronger test of the hypothesis that active coping mitigates defensive reactivity would entail measurement of startle potentiation during enactment of an avoidance response that prompts measurable HR acceleration.

The authors also noted that startle potentiation in the active response group may have occurred at least in part because the modality of the probe (acoustic) matched the modality of the anticipated aversive stimulus. When startle probes are presented in the *same modality* as an anticipated stimulus, directed attention may result in enhanced processing of the probes and startle response facilitation; conversely, allocation of attention to a nonacoustic modality may lead to inhibition of noise-elicited startle (Anthony and Graham, 1985). To establish the generality of the reported effects and to control for attention, Patrick and Berthot (1995) recommended that follow-up research with the noise anticipation paradigm be conducted using startle probes in a modality different from the stressor (e.g. tactile probes).

1.4. The present study

Building upon the work of Patrick and Berthot (1995), this study utilized tactile (airpuff) startle probes to assess whether engagement in active avoidance behavior (versus mere preparation for escape) attenuates defensive reactivity during anticipation of a loud noise stressor. Participants were assigned randomly to one of four experimental groups. *Active tapping* participants were able to avoid noise blasts contingent on their performance of a finger-tapping task. Yoked *passive tapping* participants performed the same task, but received equivalent noise exposures that were not contingent on their performance. Yoked *passive no tapping* participants received equivalent noise exposures but did not perform the tapping task. *Control tapping* participants performed the task without the threat of noise. Tactile startle probes (brief puffs of air directed bilaterally at the temple region) were presented during aversive anticipation intervals (CS+) when the motor task was being performed, and during safe anticipation intervals (CS−) in which no aversive event was awaited.

Thus, the primary aim of this research was to re-examine the emotional consequences of active coping using a yoked design and an experimental task that permitted manipulation of perceived control while precisely controlling motoric activity and noxious stimulus exposure across groups[1]. Moreover, a cross-modal probe was used so that startle potentiation could be interpreted unambiguously as

[1] In the present study, control or agency was viewed as fundamental to active coping, and the 'active' manipulation was essentially a manipulation of perceived control. Results should be interpreted in this light.

fear—rather than attention—related. This also permitted us to verify that fear-potentiated startle occurs with a tactile probe stimulus. Response-matching theory of Lang et al. (1990) implies that defensive potentiation of the startle reflex should occur regardless of the modality of the probe and the affective foreground. The one prior investigation that examined this hypothesis using tactile probe stimuli (Hawk and Cook, 1997) produced somewhat equivocal results: tactile startle reactions were enhanced during viewing of unpleasant slides in comparison to pleasant, but not neutral, slides. However, according to the response matching hypothesis, the degree of startle potentiation depends upon the net impact on the defensive response system of the probe and the cuing context. The weak startle potentiation observed in the Hawk and Cook investigation could be attributable to the fact that neither the airpuff probes (which reliably elicited blinks, but were rated as nonaversive by participants) nor the cuing context (unpleasant slide viewing) were especially potent. The present study examined whether more robust startle potentiation would be observed for tactile probes in a cuing context involving an unconditioned aversive stimulus (i.e. noxious noise).

1.5. Hypotheses

Two primary predictions were made for the startle response. First, participants in the three noise-threat groups were expected to show potentiated blink reactions during CS+ trials relative to CS− trials (Grillon et al., 1991, 1993; Patrick and Berthot, 1995); control tapping participants were not expected to show this effect. This predicted outcome would provide the first conclusive demonstration of cross-modal fear-potentiation using a tactile probe stimulus. Second, startle potentiation was predicted to be attenuated in active tapping relative to passive tapping participants as a function of the mitigating impact of active avoidance on mobilization of the defensive response system. In line with this hypothesis and based on prior findings (cf. Obrist, 1976; Szpiler and Epstein, 1976), active participants were predicted to endorse higher self-ratings of control over the noise blasts than passive participants. Active and passive tapping participants were also expected to show differential HR and EDA activity, with greater tonic HR increases predicted in the active tapping group, and greater EDA responses in the passive tapping group.

2. Method

2.1. Participants

Participants were 64 undergraduate students (32 female; ages 18–24) from Florida State University who volunteered in exchange for course credit. Data for 11 additional participants were excluded, seven for reasons of equipment malfunction (three passive tapping, three passive no tapping, and one active tapping), and two due to elective withdrawal (active tapping). Two other active tapping participants were excluded because they were unable to perform the tapping task well enough to avoid noise blasts.

2.2. Experimental design

Eight males and eight females were randomly assigned to each of four groups (active tapping, passive tapping, passive no tapping, control tapping). The main procedure involved 24 CS + and 24 CS − trials, signaled by the appearance of a horizontal string of 30 asterisks (*) or 'Os' (O), respectively, on a computer monitor. For participants in the tapping groups, the CS − trials were defined as no tapping trials. For participants in the threat groups (active tapping, passive tapping, passive no tapping), the CS − also represented safe (no noise) trials. The procedure for the CS + trials also varied across the four study groups. In the active and passive tapping groups, the CS + signaled aversive anticipation/tapping trials. In the passive no tapping group, the CS + signaled aversive anticipation without tapping. In the control tapping group, the CS + signaled tapping but not aversive anticipation.

Each trial was 15 s long, with intertrial intervals (ITIs) averaging 25 s. The visual display was centered on a 35-cm monochrome monitor, positioned at eye level approximately 1.5 m directly in front of the participant. The experiment was divided into two 20-min blocks of 24 trials each, separated by a 5-min rest period during which a questionnaire was administered. Each CS + trial began with the appearance of an asterisk string on the monitor. The 30 asterisks disappeared progressively from left to right at a constant rate of one every 0.5 s. Participants in all three tapping groups were instructed to press a microswitch immediately after each asterisk offset. This ensured that all participants tapped at the same rate on each trial (two taps per second), thereby controlling for somatic activity across groups[2]. During *CS − trials*, participants in the tapping groups were instructed not to tap, but to simply watch the display. Passive no tapping participants observed the same visual stimuli but did not perform the tapping task during either CS + or CS − trials.

Startle probes occurred during 32 of the 48 trials, at one of four possible points (5, 8, 11, or 14 s after CS onset). To reduce predictability, probes also occurred during 16 of the 48 intertrial intervals. The sequence of CS + /CS − presentations and startle probe locations was counterbalanced over trials between participants using a Latin-square design comprising eight different trial orders.

Before the main experiment, and before participants were read their group-specific instructions, a brief pre-test was performed to ensure that the groups did not differ in baseline startle reactivity. Participants viewed two presentations of the CS + display and two presentations of the CS − visual display. During one of the CS + and one of the CS- presentations, airpuff probes were presented and blinks recorded. The tapping task was not performed during this pre-test.

[2] The findings of some previous studies (e.g. Szpiler and Epstein, 1976) that manipulated active and passive coping using a tapping task were confounded by group differences in somatic activity, in that participants with control over the aversive stimulus tapped more than those without control.

2.3. Airpuff stimuli

The airpuff startle probes were generated by a tank filled with compressed breathable air connected to a Holox 0–4000 psi regulator that reduced the output to a constant flow pressure of 3 psi. A single tube (8 mm internal diameter, 1.5 m long) extended from the regulator to a 17 × 7 mm reservoir cylinder that housed two outlets for the bilateral airpuffs. The airpuffs were each 100 ms in duration and were triggered by a digital signal from the computer which simultaneously opened and then closed two 24-V electric solenoid valves (Skinner Valve # B2DA1026; 3 mm orifice) attached to the outputs of the reservoir cylinder. To eliminate the acoustic component of the solenoid trigger, the valves were located in an adjacent control room, separated from the testing chamber by a concrete wall, and encased in a sound-dampening cinder block. Two parallel lines of plastic tubing (3.5 m long, 4 mm internal diameter) passed from the solenoid valves in the control room to the testing chamber. The tubes were directed toward the temple on each side of the face approximately 2 cm behind the orbital ridge and angled away from the eyes, and were held in place by adjustable clamps attached to a customized hard-hat. Headphones producing a constant 72 dB broadband noise, filtered to omit frequencies above 110 Hz, were positioned around the helmet and over the participant's ears. This masking sound, for which parameters were established through pilot testing, was included to minimize the acoustic component of the airpuff probes.

2.4. Aversive noise stimuli

Threat group participants were told that noise blasts (0.5 s, 115 dB, rise time < 10 μs) could be presented at any time while the asterisks were on the screen. Except for control tapping participants, who did not receive noise blasts, each participant received four 'scheduled' noise blasts during the experiment: two within trial block 1, and two within trial block 2. Within each block, one scheduled blast occurred during a startle probe trial and the other occurred during a no-probe trial. This ensured that all participants, regardless of tapping performance, received at least some exposure to the aversive stimulus. Scheduled blasts occurred at varying points within the trial, from 2.5 s after trial onset up to the end of the trial. The placement of scheduled blasts within and between trials was varied across participants, using a scheme that was identical for all groups. The task criteria were designed to be subtle enough that participants in the active tapping group would be unlikely to deduce that the scheduled blasts were not contingent on their performance.

In addition to the four scheduled noise blasts, active tapping participants also received *contingent* noise blasts during CS + trials on which their performance fell below criteria that had been established through pilot testing. Specifically, a noise blast was delivered if one of two 'poor performance' criteria was met: (1) the number of incorrect taps exceeded three (to be correct, a tap had to be made within 500 ms of asterisk offset), or (2) the total number of taps during the trial exceeded the requisite number (= 30) by three or more. A computer counted the number of correct and incorrect taps, and the total number of taps, on each trial.

Contingent blasts were delivered either 14.5 s into the trial (i.e. during the time the final asterisk was on the screen), or earlier ('mid-trial'). On the first no-probe CS+ trial in which performance fell below one or the other criterion, the contingent blast was delivered 0.5 s after the failure occurred (i.e. mid-trial). On any subsequent no-probe trial in which performance fell below criterion, the contingent blast was delivered at 14.5 s. This ensured that the autonomic response data for at least five of the CS+ trials remained uncontaminated by the effects of either a startle probe or a noise blast. On probed CS+ trials in which performance fell below criterion, contingent blasts were delayed until at least 0.5 s after airpuff probe presentation. After four mid-trial blasts had occurred, any additional contingent blasts were delivered at 14.5 s. The presence of a scheduled noise blast preempted a contingent blast, so that no more than one blast occurred on any individual trial. The mean number of noise blasts (scheduled + contingent) received by participants in the active tapping group over the 24 CS+ trials was 7.56 (S.D. = 3.22; range = 4–14).

Participants in the passive tapping and passive no tapping groups were each yoked to an active group participant of the same gender and received an equivalent number of noise blasts at the same points on corresponding CS+ trials. Participants were tested in sets of four, with an active group member tested first to establish noise exposures, followed by participants from each remaining group.

2.5. Procedure

Before participating, each participant read and signed a consent form which included a brief description of the study procedures. Then, participants were administered a mood scale, the Affect Grid (Russell et al., 1989), and a series of questionnaires assessing affect-related personality traits: Anger Expression Scale (Spielberger et al., 1985); Taylor Manifest Anxiety Scale (Taylor, 1953); Fear Survey Schedule (Arrindell et al., 1984); Positive and Negative Affect Schedule (Watson et al., 1988); NEO Personality Inventory (Costa and McCrae, 1985); and Emotionality-Activity-Sociability-Impulsivity Scale (Buss and Plomin, 1975). Participants were then seated in a padded recliner in the testing chamber facing the display monitor. After attaching the physiological sensors and positioning the airpuff apparatus, the previously described baseline pre-test was conducted.

Before receiving the main procedural instructions, participants in the tapping groups observed the experimenter perform two demonstration trials of the tapping task. Active tapping participants were told that their performance on the task would determine whether or not a noise blast occurred during the asterisk display. Passive tapping participants were told that they could receive a noise blast at any time during the tapping task while the asterisks were on the screen. Passive no tapping participants were told to simply watch the visual display but were warned that on some asterisk trials they would receive a noise blast. Control tapping participants were told to perform the tapping task only during asterisk trials, and that the computer would monitor their performance. Following these instructions, the main experimental procedure began. Between blocks 1 and 2 of the experiment, participants completed a second mood rating on the Affect Grid.

At the end of block 2, participants completed a third Affect Grid. They also indicated how they felt, on average, during presentations of the CS+ and CS− using a paper and pencil version of the Self-Assessment Manikin (SAM) of Lang (1980), which yielded ratings of valence (unpleasant vs. pleasant), arousal (calm vs. excited), and dominance (helpless vs. in control). On a post-study questionnaire, participants rated the aversiveness of the experimental stimuli (i.e. masking sound, airpuff, and noise blasts), and also their ability to predict on CS+ trials whether a noise would occur, and how much control they believed they had over receipt of the noises. Upon completion of these questionnaires, participants were debriefed and given credit for their participation.

2.6. Physiological measures and data reduction

Physiological signals were recorded using Coulbourn amplifiers linked to an IBM-compatible microcomputer. The VPM software program (Cook et al., 1987) was used to control the presentation and timing of experimental stimuli and sampling, digitization, and storage of physiological data. Because most of the noise blasts were delivered during the final 0.5 s of the CS+, this portion of the trial was uniformly excluded from analyses of HR, SC, and corrugator EMG. In addition, CS+ trials on which a noise blast was delivered before this point were excluded. As a result, for the autonomic and corrugator EMG measures, an average of five CS+ trials were excluded per participant in the noise threat groups.

2.6.1. Startle response

The eyeblink response was measured from Sensor Medics miniature Ag/AgCl electrodes positioned at the orbicularis oculi muscle beneath the left eye. The raw EMG signal was amplified using a Coulbourn S75-01 bioamplifier with low and high frequency cut-offs of 90 and 250 Hz, respectively. The signal was rectified and integrated using a Coulbourn S76-01 contour-following integrator (time constant = 80 ms). Digital sampling commenced 7 s before visual cue presentation at 20 Hz, increased to 1000 Hz at 50 ms before startle probe onset, and continued at this rate for 300 ms after probe offset. Sampling then resumed at 20 Hz and continued until 10 s after the final offset of the display. The EMG data were reduced off-line using a program (Bradley, 1989) that yielded blink magnitude scores in arbitrary analog–digital (A–D) units. To control for wide variations in overall startle reactivity, raw blink data were standardized within-participants using a z-score transformation in which scores for CS+, CS−, and ITI probes were deviated from an individual's mean and divided by the corresponding standard deviation.

2.6.2. Heart rate

HR was recorded from 1-cm Sensor Medics Ag/AgCl electrodes positioned on the right and left inner forearms. The signal was filtered using a Coulbourn S75-01 bioamplifier, and a Schmitt trigger interrupted the computer each time it detected a cardiac R-spike. Interbeat intervals (ms) were recorded and reduced off-line to HR in beats per min (BPM) for the 7-s baseline preceding cue onset, the 15-s cue period, and the 10-s interval following cue offset.

Based on inspection of the autonomic response data, each CS trial was divided into an early segment (1–8 s following cue onset) and a late tonic activation segment (8–14.5 s). For HR, the early segment captured the triphasic waveform associated with initial stimulus processing. Following prior research (cf. Lang et al., 1978), this waveform was analyzed by computing *D1* (initial deceleration, s 1–2), *A* (subsequent acceleration, s 2–5), and *D2* (secondary deceleration, s 5–8), each relative to prestimulus baseline. Analysis of the more sustained (tonic) activity observed from 8 to 14.5 s was based on average level change from prestimulus baseline. Heart rate data for two participants (one active tapping, one passive tapping) were excluded from the analyses due to excessive movement artifact.

2.6.3. Skin conductance

Skin conductance (SC) was recorded from adjacent sites on the hypothenar eminence of the non-dominant hand using 1-cm Ag/AgCl electrodes filled with a Unibase-saline paste (Lykken and Venables, 1971) and connected to a Coulbourn S71-23 isolated SC coupler. The initial orienting response was computed by calculating the difference between the low point during the first second of the trial and the subsequent peak reached between 1 and 4 s (cf. Prokasy and Kumpfer, 1973). For the later segment of the trial (8–14.5 s), SC analyses were based on average level change from a 1-s prestimulus baseline.

2.6.4. Corrugator EMG

EMG activity was also recorded from the region of the corrugator muscle above the left eye using a Beckman 9852A EMG coupler. Miniature electrodes filled with electrolyte paste were positioned in accordance with published guidelines (Fridlund and Cacioppo, 1986), and EMG activity was sampled at 20 Hz throughout each trial. As with HR and SC, analyses of corrugator EMG were performed separately for the early and late segments of the trial using scores reflecting average level change during each segment from the prestimulus baseline.

2.7. Data analysis

The primary study hypotheses were tested within a mixed-model, Group × CS Type MANOVA. Preliminary analyses including probe versus no probe as a factor revealed a main effect of probe on SC and corrugator EMG response, but the effect of probe did not interact with group or CS type for any of the physiological measures. Therefore, data were collapsed across probe and no probe trials in the analyses of HR, SC, and corrugator EMG reported below.

For the physiological measures and mood ratings, differences between the four study groups were tested using planned orthogonal contrasts (POCs): (1) active tapping, passive tapping and passive no tapping vs. control tapping, (2) active and passive tapping vs. passive no tapping, and (3) active vs. passive tapping. These POCs provided direct tests of our a priori hypotheses. The first contrast assessed the impact of the threat manipulation by comparing the noise anticipation groups with the control tapping group that received no noise blasts. The second contrast examined the impact of the tapping task manipulation across the aversive anticipation groups. The third contrast specifically examined the effect of control over the noise blast.

For analyses involving only the noise-threat groups (i.e. ratings of control over the noise blast), and measures for which no specific predictions were made (i.e. trait questionnaires), one-way ANOVAs were conducted, followed by post-hoc (Tukey) tests to clarify omnibus effects.

3. Results

3.1. *Individual difference questionnaires and baseline procedure*

No significant group differences were found for any of the personality questionnaires, ruling out variations in the measured trait dimensions as an explanation for the effects reported below. One-way ANOVAs for the baseline startle data also revealed no group effects for blink magnitude or latency, $F(3,60) = 0.01$ and 1.82.

3.2. *Manipulation checks*

3.2.1. *Tapping task*

The tapping groups did not differ in the mean *total* number of taps per trial, $F(2,45) = 1.59$, but they did differ in the mean number of *correct* taps, $F(2,45) = 3.43$, $P < 0.05$. Post-hoc (Tukey) tests revealed a higher number of correct taps on average for the active tapping group ($M = 28.04$; S.D. = 0.71) than for the control tapping group ($M = 27.04$; S.D. = 1.58). The mean number of correct taps for the passive tapping group was 27.26 (S.D. = 0.95).

3.2.2. *Noise threat*

The active tapping, passive tapping, and passive no tapping groups differed in ratings of perceived control over the noise blast, $F(2,43) = 35.27$, $P < 0.01$. Post-hoc tests showed that control ratings were higher among active tapping than passive tapping or passive no tapping participants. On average, active participants perceived themselves to have more than a moderate control over receipt of noise blasts on CS+ trials, whereas passive tapping and no tapping participants perceived themselves to have virtually no control (Table 1). Groups did not differ in ratings of the predictability or aversiveness of the noise blasts.

3.3. *Anticipation procedure*

3.3.1. *Ratings of experimental stimuli*

The four study groups did not differ in affective ratings of the airpuff or masking sound, or in their ratings of the CS− stimulus (Table 1). The mean rating of the airpuff probe (3.3) was near the mid-point on the 7-point aversiveness scale, indicating that on average, participants found the probe to be moderately aversive.

In addition, a significant positive correlation was found between ratings of the aversiveness of the airpuff and the overall magnitude of raw blink responses to the probes ($r = 0.27$, $P < 0.05$), indicating that participants who reported the probes to be more aversive showed more intense probe-startle reactions.

Significant overall group effects were obtained for valence and dominance ratings of the CS+ stimulus, $F(3,60) = 2.86$ and 3.76, respectively, $P < 0.05$ (Table 1). Participants in the noise-threat groups rated the CS+ stimulus as less pleasant than did control tapping participants, $F(1,59) = 7.56$, $P < 0.05$. Dominance ratings for active tapping participants, who had control over the noise blasts. exceeded those for passive tapping participants who could not control the blasts, $F(1,59) = 4.84$, $P < 0.05$. No overall group effect was found for arousal ratings of the CS+, but the POC for the noise-threat groups versus the control tapping group was significant, $F(1,59) = 5.43$, $P < 0.05$, suggesting that the CS+ was most arousing when it was threat-related. However, it should be noted that participants in the control tapping group rated the CS+ as significantly more arousing than the CS− (but no different on dimensions of valence or dominance), indicating (a) that arousal was enhanced by performance of the tapping task per se, and (b) that valence and dominance perceptions were modified more selectively by threat than arousal perceptions.

Table 1
Mean ratings of experimental stimuli. by group[a]

Stimulus rating	Active tapping	Passive tapping	Passive no tapping	Control tapping	F ratio
Airpuff aversiveness	3.26	3.00	3.44	3.44	0.29
Masking sound aversiveness	2.13	2.62	2.69	2.00	0.61
Noise blast					
Aversiveness	4.93	5.56	5.81	-	1.38
Predictability	3.50	2.75	2.25	-	2.44
Controllability	4.79	1.50	1.25	-	35.27*
CS+					
Pleasure (valence)	2.80	2.50	2.69	3.31	2.91*
Arousal	2.87	3.31	3.38	2.50	2.60
Dominance	3.33	2.50	2.37	3.25	3.46*
CS−					
Pleasure (valence)	4.00	3.81	3.75	3.25	2.35
Arousal	1.47	1.56	1.62	1.37	0.42
Dominance	4.20	3.44	3.75	3.75	1.06

[a] Ratings of the airpuff, masking sound, and noise blast stimuli were all based on a 7-point scale with 1 representing the minimum and 7 the maximum. Ratings of the CS+ and CS− stimuli were based on a 5-point scale keyed in the same direction.

* $P<0.05$.

3.3.2. Mood ratings

As noted, Affect Grid ratings were collected at the outset of the experiment, between blocks 1 and 2 of the anticipation procedure, and upon completion of the experiment. A significant Group × Time interaction was found for *pleasantness*, $F(6,118) = 2.69$, $P < 0.05$, with POCs revealing a significant threat groups vs. control group × Time interaction, $F(2,61) = 6.52$, $P < 0.01$. Simple effects analyses indicated that although groups did not differ at the beginning or end of the experiment, pleasantness ratings were lower for the threat groups than the control tapping group during the anticipation procedure, $F(1,62) = 9.49$, $P < 0.01$.

A significant Group × Time interaction was also found for Affect Grid *arousal* ratings, $F(6,118) = 3.04$, $P < 0.05$, with POCs revealing a difference between the threat groups and the control group as a function of time. Specifically, groups did not differ at the outset of the experiment, but during and after the anticipation procedure, noise-threat participants endorsed higher ratings of arousal than control tapping participants. $F(1,62) = 13.99$ and 10.82, $P < 0.01$.

3.3.3. Startle response

A robust effect of CS Type was found for startle response magnitude, with blink reactions during CS + larger than during CS −, $F(1,60) = 51.81$, $P < 0.01$. A Group × CS Type interaction was also observed, $F(3,60) = 4.97$, $P < 0.01$[3]. POCs revealed that the noise-threat groups differed from the control tapping group in startle reflex potentiation, defined as increased blink reactivity during CS + as compared to CS −, $F(1,62) = 12.97$, $P < 0.01$. Follow-up analyses revealed that only participants in the noise threat groups showed significant startle potentiation, $F(1,47) = 6.13$, $P < 0.01$ (Fig. 1). Furthermore, reliable startle potentiation was observed in all three noise-threat groups, and POCs revealed no significant difference between the active and passive tapping groups, or between these groups and the passive no-tapping group, in the size of this effect. The pattern of results for the startle latency variable was essentially identical: A Group × CS Type interaction was found, $F(1,60) = 16.12$, $P < 0.01$, with only participants in the threat groups showing latency facilitation (i.e. faster blink reactions during CS + versus CS −).

Supplementary analyses compared probe reactions during CS + trials with reactions during intertrial intervals (ITIs), and probe responses during CS − trials with ITI responses. Startle response magnitude during CS + trials generally exceeded magnitude during ITIs, $F(1,60) = 25.27$, $P < 0.01$, but a Group × Trial Type interaction was also found, $F(3,60) = 6.20$, $P < 0.01$. Again, POCs revealed significant startle potentiation for CS + versus ITI in the noise-threat groups only, $F(1,47) = 18.45$, $P < 0.01$. On the other hand, the analysis of CS − and ITI probe trials revealed that blink responses showed a general *inhibition* during CS − in relation to ITI, $F(1,60) = 10.71$, $P < 0.01$, an effect which did not interact with Group.

[3] An initial analysis was performed with probe time (5, 8, 11, or 14 s) included as a factor. Results revealed that there was no main effect of probe time nor did this variable interact significantly with any combination of the other variables. Therefore, probe time was omitted as a factor in this analysis.

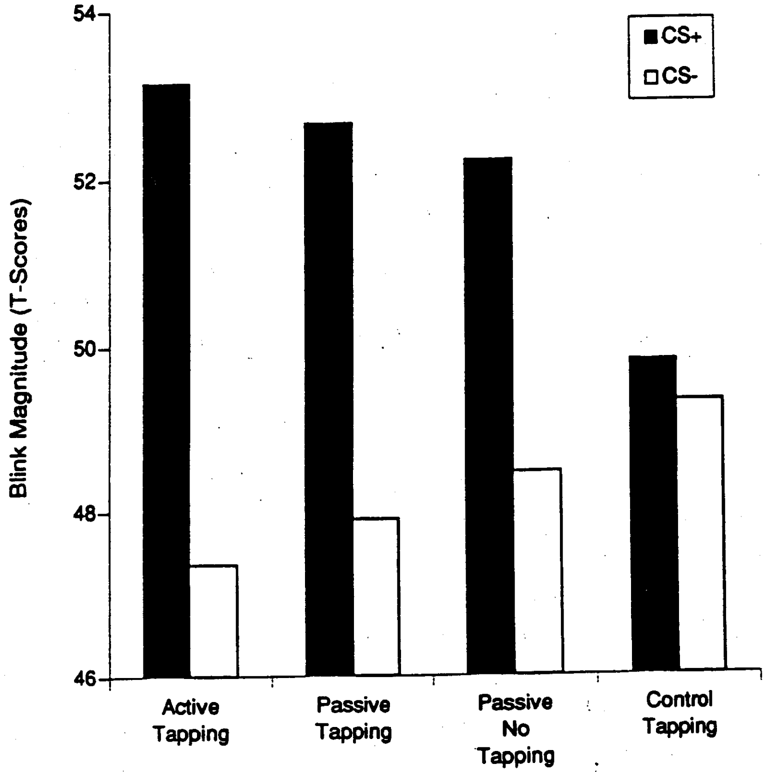

Fig. 1. Startle reflex magnitude, by group and CS type. Units of measurement are *T*-scores, computed by standardizing raw blink response scores across trials within participant, and applying a linear transformation (i.e. multiplying standard scores by 10, and adding 50).

3.3.4. Heart rate

During the early trial segment (1–8 s), all groups showed a triphasic HR response pattern. Analysis of the *D1*, *A1*, and *D2* components revealed no significant Group × CS Type interactions. However, analysis of late-interval HR change (8–15 s post CS onset; Table 2) revealed a significant main effect of Group, $F(3,58) = 7.17$, $P < 0.01$, and a significant Group × CS Type interaction, $F(3,58) = 2.82$, $P < 0.05$. For the latter effect, the only significant POC was the active vs. passive tapping × CS Type interaction, $F(1,58) = 4.23$, $P < 0.05$, reflecting reliably greater late interval HR activity during CS + (but not CS −) in the active tapping group compared to the passive tapping group (Fig. 2)[4].

[4] It appears from Fig. 2 that the HR interaction might be attributable in part to the fact that HR was lower during CS + than CS − in the passive tapping group, perhaps reflecting behavioral inhibition or 'freezing' during CS + (cf. Gray, 1987). However, because the HR difference for CS + versus CS − was not statistically significant for either the active or the passive tapping group when tested separately, the most that can be said is that the groups differed in HR reactions during the CS +.

Table 2
Late interval change score means for HR, SC, and corrugator EMG by Group and CS Type

Measure[a]	Active tapping	Passive tapping	Passive no tapping	Control tapping
Heart rate				
CS+	2.58	−0.15	−1.14	1.32
CS−	1.59	1.21	−0.03	0.26
Skin conductance				
CS+	0.27	0.27	0.30	0.12
CS−	0.07	0.04	0.00	0.06
Corrugator EMG				
CS+	0.56	0.39	0.22	0.19
CS−	−0.43	0.00	0.08	−0.24

[a] Units of measurement are: heart rate, beats per min; Skin conductance, μS; Corrugator EMG, μV.

3.3.5. Skin conductance

Analyses of initial SC response revealed a main effect of CS Type, $F(3,60) = 35.21$, $P < 0.001$, with larger responses for CS + than CS − trials, but no effect of Group and no Group × CS Type interaction. Similarly, during the late trial segment there was a main effect of CS Type, $F(1,60) = 2.29$, $P < 0.01$, and only a

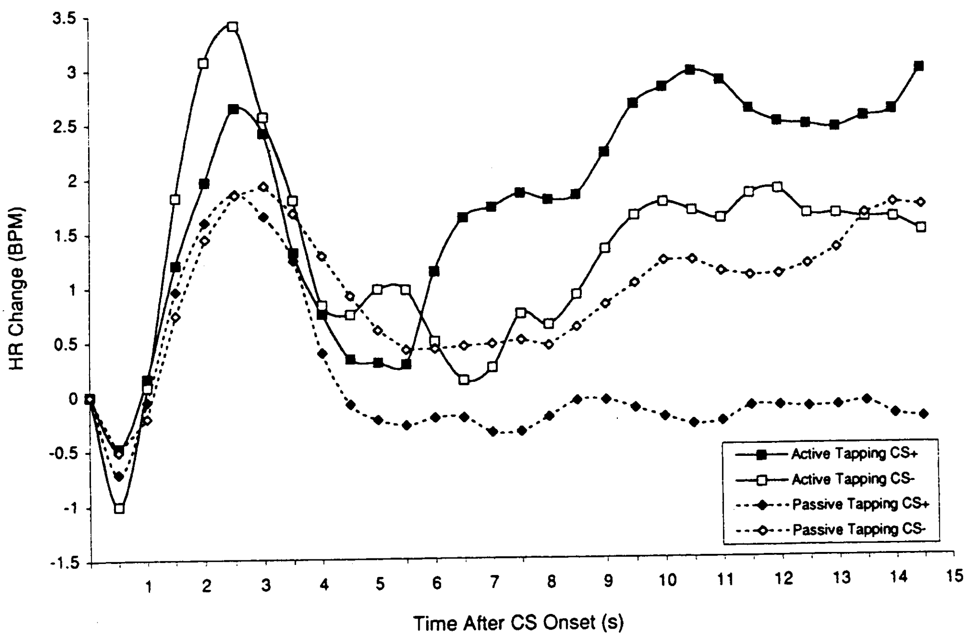

Fig. 2. Average HR waveforms for active tapping and passive tapping groups, by CS type. Waveforms reflect mean HR changes (in beats per min) for each half-s between CS onset and the last half-s before CS offset.

trend toward less CS+/CS− difference in the control tapping group than in the aversive noise groups, $F(1,62) = 3.33$, $P < 0.10$ (Table 2).

3.3.6. Corrugator EMG

During the initial trial segment (1–8 s) there was a main effect of CS Type, $F(1,60) = 33.41$, $P < 0.01$, and a significant Group × CS Type interaction, $F(3,60) = 5.88$, $P < 0.01$. POCs revealed a greater CS+/CS− difference in the active tapping group than in the passive tapping group, $F(1,60) = 8.55$, $P < 0.01$, and a larger difference in the combined active and passive tapping groups than in the passive no tapping group, $F(1,60) = 7.72$, $P < 0.01$. Results for the latter segment of the trial (8–15 s) were similar. There was a main effect of CS Type, $F(1,60) = 33.51$, $P < 0.01$, and a significant Group × CS Type interaction, $F(3,60) = 3.24$, $P < 0.01$. POCs for this portion of the trial revealed only that the magnitude of the CS+/CS− difference in the active tapping group exceeded that in the passive tapping group, $F(1,60) = 6.36$, $P < 0.05$ (Table 2).

4. Discussion

The principal aim of this study was to assess changes in emotional state during active avoidance of a noxious stimulus using the startle reflex as a measure of defensive reactivity. To achieve this objective, it was essential that the threat manipulation used in CS+ trials be effective in evoking a defensive emotional state. Evidence for the efficacy of this manipulation was provided by the self-report data. Ratings of the experimental stimuli revealed that participants rated the noise blasts as moderately to highly aversive, and in comparison with participants in the control tapping (no noise) group, those in the aversive anticipation groups reported heightened unpleasantness and arousal during presentation of the CS+ compared to the CS− stimulus. Furthermore, on ratings of mood state collected over the course of the experiment, participants in the noise-threat groups reported greater levels of unpleasantness and arousal than participants in the control tapping group.

As predicted, the efficacy of the threat manipulation was also evidenced by the fact that participants in the noise-threat groups showed significant blink magnitude potentiation and latency facilitation during CS+ trials relative to CS− trials, an effect not observed in the control tapping group. Supplementary analyses revealed that startle was also potentiated in the noise groups during CS+ trials in comparison to intertrial intervals (ITIs). The finding of significant blink enhancement during CS+ trials in the active and passive tapping groups, but not in the control tapping group, indicates that startle potentiation was linked to the aversiveness of the cue in the former conditions and not to performance of the tapping task per se. The finding of significant blink potentiation in the passive no tapping group further supports this interpretation.

Blink reflex potentiation was observed during CS+ periods in the noise-threat groups despite the fact that the startle probes were presented in a sensory modality (tactile) different from that to which participants were instructed to attend (visual) and in which the aversive stimulus was presented (acoustic). During CS − periods blink reactions for all groups were *smaller* than during ITIs, suggesting an inhibitory influence of a non-aversive attentional foreground on reflex responding (cf. Anthony and Graham, 1985). That the direction of startle modulation during CS + exposure was opposite to this implies that the negative emotional reaction to the warning cue overrode any influence of cross-modal attention. Elsewhere, Grillon et al. (1991, 1993) have demonstrated cross-modal fear-potentiation for acoustic startle probes during anticipation of a noxious tactile stimulus (shock). The present study provides a conclusive demonstration of cross-modal startle potentiation in humans using tactile probes. Moreover, the present findings lend support to the notion that defensive potentiation of the startle reflex should occur independently of the modality of the probe and of the negative emotional foreground (Lang et al., 1990).

Hawk and Cook (1997) previously reported that blink reactions to airpuff probes were greater during viewing of unpleasant pictures in comparison to pleasant pictures, but not in relation to neutral pictures. In contrast, the present study did find robust startle potentiation during presentation of an aversive CS + in comparison with a neutral CS −. One difference between the two studies was in the nature of the aversive stimulus: A warning cue for an unconditioned stressor (noxious noise) may more reliably prime a defensive reaction than unpleasant pictures, which are not tied to immediate physical discomfort and which commingle strong interest/engagement with aversiveness (Cuthbert et al., 1996). Also, participants in our study (regardless of group) rated the airpuff probes as moderately aversive, whereas Hawk and Cook's participants rated the airpuffs as nonaversive, and in the present study individuals who rated the airpuffs as most aversive showed the strongest probe-startle reactions. Because the parameters of the airpuff stimulus (pressure, duration) were ostensibly similar in the two studies, it may be that reactions to this type of stimulation vary with context: unpredictable probes may be experienced as less unpleasant under circumstances that are more variable and stimulating (e.g. slide viewing) than those of the present study, in which foreground stimuli were not inherently interesting and in which probes distracted from task performance. In any case, it appears that in the present context, where foreground cues signaled a proximal noxious event and in which the airpuff probes themselves were perceived as aversive, robust startle potentiation was observed—implying the presence of an effective defensive 'response match' (cf. Lang et al., 1990).

This study was the first to examine the impact of execution of an overt behavioral response on affective modulation of the startle response. Prior investigations of the fear-potentiated startle effect in humans have employed paradigms such as slide viewing and imagery that involve no overt behavioral responding, and it has been speculated that fear-potentiation might be precluded by overt action such as that involved in actively avoiding an aversive stimulus (Lang, 1995). However, our prediction that startle potentiation would be reduced in the active compared to the passive tapping group was not supported. The present results therefore indicate that fear-potentiated startle can occur during 'modulated' avoidance behavior (although it remains likely that different rules would apply for instinctual fight/flight behavior;

Lang et al., 1997). This points to the potential utility of the startle reflex for probing affective processes during continuous performance tasks such as conflict (reward–punishment) learning (Widom et al., 1985; Newman and Kosson, 1986), the emotional Stroop procedure (cf. Williams et al., 1996), and the delay, vigilance, and distractibility tasks of the Gordon Diagnostic System (Gordon et al., 1996).

A final objective of this study was to develop a paradigm that permitted manipulation of active avoidance behavior and perceptions of control over aversive stimulation while equating exposure to the noxious stimulus and motor activity across the relevant comparison groups. Aversive stimulation was equalized by using a yoked experimental design, and somatic activity was controlled by regulating tapping frequency via an objective performance criterion. The tapping data revealed that the groups performing the task did not differ on the total number of taps per trial, suggesting that somatic activity was constant across groups. This represents an improvement over some prior studies (e.g. Szpiler and Epstein, 1976) in which group differences in HR were confounded by differences in somatic activity associated with task performance.

Furthermore, while being matched for somatic activity and exposure to the noise blasts, active tapping participants endorsed significantly higher ratings of control over the noise blast and higher ratings of dominance in relation to the CS+ cue than passive tapping participants. Associated with this effect, and consistent with prediction and prior findings on active avoidance (e.g. Obrist, 1976; Fowles, 1980), active tapping participants also displayed significantly greater HR activity during CS+ periods than passive tapping participants—an effect opposite to the deceleratory response observed during *preparation* for avoidance (Patrick and Berthot, 1995). Yet, despite this strong evidence for the efficacy of the active avoidance manipulation, the hypothesized attenuation of skin conductance response and startle potentiation in active tapping participants relative to passive tapping participants was not observed.

For skin conductance, the overall effect of CS type (CS+ > CS−) was highly significant, but analyses revealed that the difference in the CS+/CS− effect for the threat groups versus the control tapping group only approached significance. This suggests that other factors (e.g. orienting, stimulus discrimination, activity) were more influential in mediating skin conductance reactivity to the CS+ in this experiment than threat per se. Considering the robust effect of the threat manipulation on self-report and startle reflex measures, the corresponding marginal effect for skin conductance highlights the ambiguities associated with electrodermal activity as an index of defensive mobilization. Experimental research indicates that skin conductance reactivity is a nonspecific index of sympathetic arousal (Greenwald et al., 1989) that is mediated cortically (Tranel and Damasio, 1994) and which reflects negative affect only indirectly. Relevant to this, Hamm and Vaitl (1996) reported evidence of electrodermal conditioning in both nonaversive and aversive conditioning procedures, but only amongst participants who reported awareness of the CS/US contingency; in contrast, startle potentiation (CS+ > CS−) developed for aversive conditioning only, whether participants recognized the contingency or not. Thus, it is conceivable that electrodermal effects in some prior studies of active avoidance might reflect alterations in higher processing activities during threat, rather than differences in primary defensive reactivity. Consistent with this interpretation, ratings of CS + arousal in the present study were related less selectively to threat than ratings of valence and dominance.

In contrast, a compelling body of literature indicates that startle reflex potentiation indexes mobilization of the aversive motivational system. Fear-potentiated startle has been observed during aversive states evoked by various types of stimuli (Vrana et al., 1988; Cook et al., 1991; Grillon et al., 1991, 1993), and animal researchers have identified fear-related brain systems as playing a critical role in the phenomenon (Davis, 1986). In the present study, robust startle potentiation was observed in the noise-anticipation groups, and this effect (as noted above) was clearly tied to the threat manipulation. In view of demonstrations that the degree of startle potentiation covaries with gradations in negative affect (e.g. Cuthbert et al., 1996; Patrick et al., 1996), a reliable decrease in startle potentiation should have accompanied a reliable attenuation in negative emotional reactivity. That the active tapping group failed to show even a hint of a decrease in startle potentiation (i.e. the absolute size of the effect in this group actually exceeded that for the other noise-threat groups) strongly suggests that the active avoidance manipulation—while sufficient to influence autonomic responding and participants' perception of control over the aversive stimulus—did not attenuate defensive reactivity at a primary response level. (The finding that corrugator EMG response to CS + versus CS – was greater among active tapping participants further argues against the possibility that negative affectivity was reduced in this group, but it should be acknowledged that heightened concentration during contingent tapping could have played some role in this effect.)

Lang et al. (1990) theorized that the startle reflex is modulated at a primary, or *strategic*, level of emotional response that defines the general direction of behavior (i.e. appetitive or defensive) and the level of energy to be expended. This strategic orientation can be expressed in different ways depending upon the *tactical* demands of the situation and the learning history of the organism. A threatening stimulus can, for example, prompt behavioral withdrawal or vigorous attack as a function of the context. Although the overt, tactical expression differs, both behaviors are presumed to be mediated by an underlying negative, defensive state.

Within this framework, the results of this study suggest that the active avoidance manipulation, while effective in modifying tactical components of the negative emotional reaction—including appraisals of control over the aversive stimulus and HR activity—was not sufficient to mitigate defensive response at the primary strategic level. From this perspective, group differences in HR might be interpreted as reflecting differences in attentional set (i.e. predominance of sensory rejection versus sensory intake) as a function of whether motor behavior is functional or purely incidental (cf. Lacey, 1967; Jennings et al., 1971). The present results thus suggest that the HR and startle response measures were differentially informative in this context, with HR providing a sensitive index of variations in response set, and startle reflecting the underlying defensive disposition common across tactical sets (cf. Lang et al., 1990).

It is probably the case that the impact of active coping on defensive reactivity is moderated by other parameters of the avoidance situation, and by individual difference factors (Averill, 1973; Thompson, 1981). Regarding the context of avoidance, there exists evidence that in addition to control, parameters such as stressor predictability and success feedback may determine whether active coping affects negative emotional response (Weiss, 1971a,b,c). Therefore, it is possible that in an active avoidance context where all three parameters were optimized, defensive startle potentiation would be measurably attenuated. In addition, specific personality traits may moderate the relationship between coping behavior and defensive reactivity. For example, individuals high on traits such as locus of control and self-efficacy may show greater reduction in negative emotional reactivity during active avoidance than individuals low on these dimensions (Archer, 1979; Gerin et al., 1995). Trait differences of this kind, and also differential learning histories, may prompt appraisals of aversive situations as alternatively threatening or challenging (Lazarus and Folkman, 1984), which may in turn influence the self-report, physiological, and behavioral consequences of active avoidance behavior (Tomaka et al., 1993).

An exploration of the full range of factors mediating the relationship between negative emotional reactivity and coping is clearly beyond the scope of a single investigation. Nonetheless, the present study—incorporating a careful yoking procedure and a unique index of defensive reactivity—embodies some useful advances in this regard. The coping/startle methodology described here could be extended to assess changes in emotional response as a function of predictability and mastery (e.g. by manipulating task difficulty and success feedback over experimental trials). It could also be used to assess the effects of alternative coping strategies in clinical subgroups believed to exhibit pathological patterns of emotional responding, such as hypertensive patients and psychopathic criminals. Using these procedures, it should be possible to gain some new insights into the effects of trait and situational variables on defensive reactivity during active avoidance, and to readdress some important unresolved questions in this field.

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