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Effects of Predictability of Shock Timing and Intensity on Aversive Responses

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Abstract

An important characteristic of aversive stimuli that determines emotional responses is whether the stimuli are predictable. Human laboratory studies in this area have typically operationalized predictability as being able to predict the occurrence of aversive events, but animal studies suggest that being able to predict other characteristics of the stimuli may also play a role in aversive responding. To examine this, the present study examined two characteristics: the timing and intensity of aversive stimuli. Specifically, participants were randomly assigned to receive shocks that were either predictable or unpredictable in terms of when they would occur (timing) and/or their intensity. Indicators of aversive emotional responses were EMG startle responses and subjective anxiety ratings. Results revealed that aversive responding was elevated for unpredictable timing and intensity suggesting that the predictability of both characteristics play a role in aversive responding (though the effects for timing were stronger). In sum, the anxiogenic effects of unpredictability may generalize to situations beyond unpredictable timing.

Keywords

Predictability; Fear-Potentiated Startle; Anxiety; Psychophysiology

1. Introduction

Researchers have long been interested in emotional responsivity to unpredictable aversive stimuli or events (Barlow, 2000; Davis, 2006; Grillon et al., 2004; Imada and Nageishi, 1982). Both predictable and unpredictable aversive stimuli induce negative emotional states (Fanselow, 1980; Grillon, 2002), but animal studies suggest that unpredictable aversive stimuli are associated with more disturbed physiological responding, such as muscle tension and ulceration (Mineka and Kihlstrom, 1978; Seligman, 1968; Seligman and Maier, 1967; Weiss, 1970), and are more likely to evoke avoidance behavior (Frankel and Vom Saal, 1976; Lockard, 1963; see Imada and Nageishi, 1982). Emotional reactions to predictable and unpredictable aversive stimuli have also been shown to be mediated by overlapping but

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distinct neural systems (Davis, 2006; Gray and McNaughton, 2000). Moreover, a heightened sensitivity to unpredictable aversiveness has been proposed to be a key variable in the etiology and maintenance of anxiety disorders, particularly post-traumatic stress disorder and panic disorder (Craske et al., 2009; Grillon, 2008a; Grillon et al., 2008; 2009).

One of the ways psychophysiological researchers have examined unpredictability is by measuring startle response while individuals anticipate either a predictable or unpredictable aversive stimulus (e.g., a shock). The startle response is a well-documented indicator of aversive system activation (Lang, 1995). It is modulated by aversive emotional states, such as anxiety (Lang et al., 1998), and its neurobiology has been studied extensively (Koch, 1999).

Grillon and colleagues developed a novel startle paradigm to measure aversive responses to unpredictability (Grillon et al., 2004; 2008; 2009). The paradigm consists of three within-subjects conditions (i.e., No Threat, Predictable Threat, Unpredictable Threat), and during each condition participants are presented with a geometric cue several times on a computer screen while they receive startle probes (e.g., brief, loud acoustic probes presented through headphones). During the “No Threat” condition, participants are never in danger of receiving the aversive stimulus (e.g., shock). During the “Predictable Threat” condition, participants can only receive the aversive stimulus while the geometric cue is present on the screen and are safe from the aversive stimulus when it is absent (i.e., during the inter-trial interval [ITI]). During the “Unpredictable Threat” condition, participants can receive the aversive stimulus while the geometric cue is on the screen *or* when it is absent (i.e., the cue does not predict the aversive stimulus). In short, participants can predict when they will receive the aversive stimulus during the Predictable Threat condition but cannot predict its occurrence during the Unpredictable Threat condition. Studies that have used this paradigm suggest that those with certain anxiety disorders show elevated startle responses to unpredictable threat but not predictable threat (Grillon et al., 2008; 2009). Additionally, substances such as alcohol and benzodiazepines appear to only affect responses to unpredictable threat, suggesting that the two threats are pharmacologically distinct (Grillon et al., 2006; Moberg and Curtin, 2009). These latter findings also support the theory that predictable aversiveness yields a qualitatively different response from unpredictable aversiveness (often labeled fear and anxiety, respectively; Davis, 2006; Grillon, 2008a).

To date, the majority of research examining the effects of predictability in humans has focused on manipulating the timing of aversive stimulus delivery (i.e., whether the person is able to predict the onset of the aversive stimulus). However, not being able to predict other characteristics of aversive stimuli may also play a role in aversive responding. Indeed, animal studies of aversive responding have manipulated the predictability of multiple features of aversive stimuli (see Imada and Nageishi [1982], for review). For example, a few studies have manipulated whether the intensity of the aversive stimulus is predictable or unpredictable. Using a classic shuttle-box experiment, Marlin et al. (1979) presented rats with shocks that were either of predictable or unpredictable intensity and animals were significantly more likely to avoid the latter. Fujii et al. (1994) conducted a similar experiment and found that unpredictable intensity induced a suppression of licking behavior (a behavioral indicator of an aversive emotional state). In both of these studies, the predictability of the shock’s intensity was the only parameter that was manipulated as the onset (timing) of the shocks was always predictable. This suggests that the effects of predictable intensity may be independent of predictable timing.

The aim of this study is therefore to compare in humans two cases of unpredictability – timing and intensity. Specifically, we will adapt the startle paradigm of Grillon and colleagues (Grillon et al., 2004, 2008) to manipulate the predictability of the timing and intensity of aversive stimuli. This will allow us to examine the independent and interactive effects of unpredictable timing and intensity on startle and subjective responses.

While the hypotheses for timing manipulation are essentially to replicate what others have reported in the literature (i.e., elevated response in the unpredictable condition during the ITI), the hypotheses for the intensity manipulation are less clear. We expect that those in the unpredictable intensity groups would experience the task as more aversive than those in the predictable intensity groups, but it is unclear whether this will manifest itself as elevated responses during the ITI, cue, or both. Within our design, the two Intensity groups are balanced on Timing (i.e., the variable which specifically manipulates the meaning of the cue). Thus, the cue and the ITI should have the same meaning in both Intensity groups. However, as this is an exploratory manipulation, we hesitate making a strong hypothesis regarding which conditions will be affected by the intensity manipulation.

The present study also adapted the Grillon et al. (2004; 2008) paradigm in another significant way. Because the aforementioned paradigm is a within-subjects design, it is possible that the effects of one condition may carry-over into the effects of another (Greenwald, 1992). For example, responses to the unpredictable threat condition may influence responses to the predictable threat condition, as the latter is likely to be preferred according to the “preference-for-signaled-shock phenomena” (Badia et al., 1979; Fanselow, 1980). Also, consistent with the carry-over effect hypothesis, several studies using the Grillon and colleagues paradigm reported that participants startle responses were elevated during the ITI of the predictable condition relative to the ITI of the no threat condition (Grillon et al., 2004; 2008). That is, even though participants were “safe” during the ITI of the predictable condition (i.e., the cue is not on the screen), they nonetheless exhibited an elevated startle response. Grillon et al. (2004) suggested that this elevated response may reflect anticipation of the cue in the predictable condition (and possibly contextual anxiety; Fanselow, 2010), although it may have also reflected carry-over effects from the unpredictable condition.

In order to rule out carry-over effects in the present study, we changed the Grillon et al. (2004; 2008) design so that the predictable and unpredictable conditions were between-subjects rather than within-subjects conditions. Additionally, our intensity manipulation (predictable vs. unpredictable) was a between-subjects manipulation. An added advantage of examining both parameters of interest (timing and intensity) as between-subjects factors is that it allowed a more direct comparison of their independent and interactive effects on aversive responding.

2. Material and Methods

2.1 Participants

One-hundred fifteen undergraduates from a large Midwestern university participated in the study for course credit. The sample was 64.5% female and had an average age of 19.51 (*SD*=1.35). The sample was ethnically diverse with 37.3% Caucasian, 5.5% African-American, 19.1% Hispanic, 25.5% Asian, and 12.7% of other ethnic descent. All participants gave informed consent.

2.2 Stimuli and Physiological Responses

Stimuli were regulated by Contact Precision Instruments (London, UK) and startle data were recorded using a PC-based acquisition system (Neuroscan 4.3). Startle response was operationalized as the eyeblink response to 50ms, 103db bursts of white noise presented binaurally through headphones with near instantaneous rise time. The startle eyeblink was recorded using two electrodes placed over the obicularis oculi muscle underneath the right eye and collected with a bandpass of 10–200 Hz at a sampling-rate of 1000 Hz. Ground and reference electrodes were placed along the midline of the forehead and back of the neck, respectively. The aversive stimulus was an electric shock presented for 400 ms to the participant's non-dominant wrist at levels described in section 2.3.

2.3 Procedure

Following electrode placement, all participants were seated in a sound-attenuated booth approximately 1m from a 19-inch computer screen. Participants first completed a 2.5 minute baseline task where they were presented with 9 acoustic startle stimuli (and no shocks). This allowed participants to habituate to the acoustic noise probes to reduce initial exaggerated startle responses. Next, shock intensity was determined for each participant using a work-up procedure in which participants received increasing levels of shock, until the shock was described as “highly annoying but not painful.” We determined shock levels ideographically to be consistent with prior studies (Grillon et al., 2004) and to ensure that subjects experienced the shocks as aversive. This step is important because there are large individual differences in the perceived aversiveness of electric shocks (Rollman and Harris, 1987). Next, participants received task instructions.

2.3.1 Experimental Task—The paradigm was modeled after the task designed by Grillon and colleagues (Grillon et al., 2004, 2008, 2009). The task had one within-subjects condition – Shock (S) vs. No Shock (NS). During each of these 90-s conditions, three 8-s cues appeared on the screen (red square during S; blue circle during NS) and the rule for the condition was always presented at the bottom of the screen as a reminder to the participant. In between cues, inter-trial intervals (ITIs) ranged from 16–24 seconds. No shocks were presented during the NS condition. The rule for the S condition varied depending on the participants group.

Participants were randomly assigned via latin-square to one of four groups in a 2 × 2, between-subjects design consisting of the factors: Timing (Predictable [P-Timing] vs. Unpredictable [U-Timing]) and Intensity (Predictable [P-Intensity] vs. Unpredictable [U-Intensity]). During the S condition, participants in the P-Timing groups received a shock only when (and always when) the cue was on the screen, and participants in the U-Timing groups received shocks at any time (i.e., cues did not predict shock for the U-Timing group). Participants in the P-Intensity groups received shocks that were at their shock workup intensity level and participants in the U-Intensity groups received shocks that were either at their workup intensity level or lower (specifically, ¾ or ½ of the workup intensity). Of note is that participants in the U-Intensity group did not know what intensity level they would receive, nor what the possibilities were. They were only told that the shock level would be at the workup intensity (i.e., highly annoying but not painful) or lower.

The experiment consisted of two 10-minute blocks separated by a 5–10 minute break. During each block, S and NS conditions were presented in one of two alternating orders: NSNSNS or SNSNSN (counterbalanced). In between each condition was a 10-s rest period (and fixation cross), during which participants did not receive any shocks or startle probes. During the whole experiment, participants received 64 startle probes (32 per block), with 16 each during NS-cue, NS-ITI, S-cue, and S-ITI. During the experiment, participants received 18 shocks (9 per block). U-Timing participants received 9 shocks each during the ITI and cue, and P-Timing participants, as per the rule of the P-Timing condition, received all 18 shocks during the presentation of the cue (one per cue). For P-Timing participants, shocks were delivered between 3 and 7 seconds following cue onset. For all participants, to ensure that each startle response was not affected by an immediately preceding shock, the time interval between a shock and the following startle probe was always greater than 11-s. At least 6 seconds always passed between startle probes. Additionally, the time interval between startle probes and preceding events (probes or shocks) was balanced across the conditions (NS-cue, NS-ITI, S-cue, and S-ITI) and groups (P-Timing, U-Timing, P-Intensity, U-Intensity). Similarly, the time interval between shocks and subsequent startle probes was balanced across groups as well.

2.3.2 Emotion Ratings—After the completion of each block, participants rated their anxiety levels during cue and ITI in both NS and S conditions. Participants also rated the intensity of the shocks, and the degree to which they would avoid experiencing the electrical stimulation again. Ratings were made on a scale from 0 (“not at all” for anxiety and intensity; “would definitely avoid” for avoidance) to 7 (“extremely” for anxiety and intensity; “would definitely not avoid” for avoidance).

2.4 Data Analysis

Blinks were scored according to guidelines provided by Blumenthal et al. (2005). Startle EMG was rectified and then smoothed using an FIR filter (low pass cutoff of 40 Hz, 12 dB/oct roll-off). Peak amplitude of the blink reflex was determined in the 20–100 ms time frame following the startle probe onset relative to baseline (average baseline EMG level for the 50-ms preceding the startle probe onset). Each blink was analyzed for its conformity as per established guidelines (Blumenthal et al., 2005). Five participants data were excluded from analyses because they had fewer than 3 scoreable blinks within a condition, making the final sample of 110 participants (64.5% female). The N’s in each group were as follows: P-Timing and P-Intensity (*N*=28); P-Timing and U-Intensity (*N*=26); U-Timing and P-Intensity (*N*=27); and U-Timing and U-Intensity (*N*=29). The groups did not differ on age, gender, or ethnicity (all *p*’s > .25). Below, we report results for blink magnitude (i.e., condition averages which include zeroes for non-responses), although similar patterns of results were found with amplitude.

We conducted a mixed design ANOVA with two within-subjects variables (Condition [S vs. NS] and Cue [Cue vs. ITI]) and two between-subjects variables (Timing [P vs. U] and Intensity [P vs. U]). Significant results were followed-up with planned comparisons. When Block (Block 1 vs. Block 2) was added as an additional within-subjects factor, there was no main effect for Block, nor any interactions with any of the within subjects variables (all *p’s*>.51). More importantly, there were no interactions between Block and the two between-subjects factors of interest - Intensity and Timing (all *p*’s >.20) - suggesting that these independent variables did not yield different effects from the first block to the second. Thus, all analyses were conducted with results averaged across both blocks. Given the finding that females are more likely to exhibit higher startle in response to unpredictable threat (Grillon, 2008b), all ANOVAs included gender as a covariate. However, when gender was removed from the models, the general pattern of results remained (although slightly weaker). Parallel analyses were done for both startle response and subjective anxiety.

3. Results

Participants rated the shocks as moderately intense (*M* = 4.59, *SD* = 1.00) and indicated that they would prefer to avoid receiving the shocks again (*M* = 2.74, *SD* = 1.18). This suggests that the shocks had the intended aversive effect. Additionally, a Timing × Intensity ANOVA on these measures did not yield any main effects for Timing or Intensity (*p*’s > .25), or a Timing × Intensity interaction (*p*’s > .26), suggesting that groups did not differ in their perception of the shocks. The groups also did not differ on gender, age, or ethnicity.

In order to determine whether the four randomized groups were comparable in overall startle reactivity, we examined the average startle response of the four groups to the 9 baseline/

habituation startle probes in a Timing × Intensity between subjects ANCOVA (adjusted for gender). There were no main effects for Timing, Intensity or their interaction (all p's > .27) suggesting that randomization was effective and the groups had comparable overall startle reactivity.

Below, we report the results for startle and self-report anxiety ratings separately.

3.1 Startle

3.1.1 Unpredictable Timing—There were significant Timing × Cue and Timing × Condition interactions (both *p*'s <.05), but these 2-way interactions were qualified by a significant 3-way Timing × Cue × Condition interaction, $F(1, 105) = 9.29$, $p < .01$, $\eta_p^2 = .08$. To follow-up this 3-way interaction, we examined the S and NS conditions separately for the two Timing groups (see top of Figure 1). During the S condition, this interaction was significant $F(1, 107) = 13.87$, $p < .001$, $\eta_p^2 = .12$. As expected, compared to those in the U-Timing group, those in the P-Timing group showed a greater increase in startle from the ITI to the cue. Also as expected, during the NS condition, the Timing × Cue interaction was not significant, $F(1, 107) = 0.13$, *ns*, suggesting that the Timing manipulation had a specific effect on the S condition only. The omnibus ANOVA yielded no main effect for Timing, suggesting that the two groups yielded comparable overall startle responses, $F(1, 105) = 1.03$, *ns*.

As mentioned in the introduction, previous studies using a within-subjects version of the paradigm (Grillon et al., 2004; 2008) showed an increase in startle during the ITI of the predictable condition (relative to the ITI of the NS condition) - even though participants were ostensibly safe during this period. We therefore examined whether this was the case with our between-subjects design by examining group differences during the ITI. Results indicated that those in the P-Timing group did not exhibit elevated startle during the ITI of the S condition relative to ITI of the NS condition, $F(1, 52) = 0.08$, *ns*. Additionally, consistent with previous studies (Grillon et al., 2004; 2008), similar analyses with participants in the U-Timing group showed an elevated startle during the ITI of the S condition relative to the ITI of the NS condition, $F(1, 54) = 5.19$, $p < .05$, $\eta_p^2 = .06$.

3.1.2 Unpredictable Intensity—Similar to the Timing results, there was a significant Intensity × Cue interaction, $F(1, 105) = 4.96$, $p < .05$, $\eta_p^2 = .04$. However, the Intensity × Condition × Cue interaction only approached a trend, $F(1, 105) = 2.58$, $p = .11$, $\eta_p^2 = .02$. Even though this 3-way interaction only approached a trend, we examined the Intensity × Cue interaction separately in the S and NS condition to parallel the Timing analyses and in order to examine whether the pattern of results was different between the S and NS conditions (see Figure 2). During the S condition, compared to those in the U-Intensity groups, those in the P-Intensity groups showed a greater increase in startle from the ITI to the cue (Intensity × Cue interaction: $F[1, 107] = 4.34$, $p < .05$, $\eta_p^2 = .04$). During the NS condition, the 2-way interaction was not significant ($p = .61$). Thus, the significant 2-way Intensity × Cue interaction was largely driven by group differences during the S condition. Similar to the Timing analyses, the omnibus ANOVA yielded no main effect for Intensity, suggesting that participants in the two Intensity conditions yielded comparable overall startle responses, $F(1, 107) = 1.04$, *ns*.

3.1.3 Intensity × Timing—These analyses revealed a Timing × Intensity interaction between-subjects effect that approached significance, $F(1, 105) = 3.47$, $p = .06$, $\eta_p^2 = .03$ (see Figure 3). Because an *a priori* aim was to examine the interactive effects of Timing × Intensity, we followed-up this trend using planned comparisons of the four groups. The P-Timing/P-Intensity group had lower startle during the experiment than the P-Timing/U-

Intensity group ($F[1, 51] = 4.90$, $p < .05$, $\eta_p^2 = .09$), U-Timing/P-Intensity group ($F[1, 52] = 4.37$, $p < .05$, $\eta_p^2 = .08$), and the U-Timing/U-Intensity group at a trend level ($F[1, 54] = 2.88$, $p < .10$, $\eta_p^2 = .05$). The latter three groups did not differ from each other. There were no Timing × Intensity interactions with any of the within-subjects effects (i.e., Condition, Cue, Condition × Cue (all *p*'s > .61).

3.2 Subjective Anxiety

Similar to the startle results, there was a significant Timing × Condition × Cue interaction, $F(1, 104) = 26.40$, $p < .001$, $\eta_p^2 = .20$ (see bottom of Figure 1). Also similar to the startle data, during the NS condition, the Timing × Cue interaction was not significant, $F(1, 106) = 0.01$, *ns*, but, during the S condition, this interaction was significant $F(1, 107) = 37.40$, $p < .001$, $\eta_p^2 = .26$. Specifically, those in the P-Timing group reported more anxiety during the cue vs. the ITI, while those in the U-Timing group reported comparable anxiety during the cue and ITI. The omnibus ANOVA also yielded a main effect for Timing, with those in the U-Timing group reporting higher overall anxiety compared to those in the P-Timing group, $F(1, 104) = 4.42$, $p < .05$, $\eta_p^2 = .04$.

Similar to the startle analyses, we also examined whether subjective anxiety was elevated during the ITI of the S condition for P-Timing participants. Unlike the startle data, individuals in the P-Timing group reported greater anxiety during the ITI of the S condition relative to the ITI of the NS condition, $F(1, 52) = 8.27$, $p < .01$, $\eta_p^2 = .14$. It is important to note, however, that this effect for the P-Timing group was smaller than that of the U-Timing group, $F(1, 54) = 39.56$, $p < .01$, $\eta_p^2 = .42$.

Regarding the results for Intensity and Timing × Intensity, there were no significant main effects or interactions with any within-subjects factors (all *p*'s > .34). Thus, Timing influenced subjective anxiety, but Intensity did not.

4. Discussion

Unpredictability has been operationalized in animal studies as a "class of situations involving elements of irregularity, [or] lack of lawfulness…about environmental events" (Imada and Nageishi, 1982, p. 574). The present study sought to examine two of these "classes" – unpredictable timing and unpredictable intensity. Specifically, we examined whether startle and subjective anxiety were potentiated differently when participants did not know a) when they would receive a shock and/or b) the intensity of the shock. To our knowledge, this is the first investigation in humans that has examined multiple classes of unpredictability within the same study.

Individuals assigned to the P-Timing group exhibited different responses during the experimental paradigm than those assigned to the U-Timing group. Specifically, relative to those in the U-Timing group, participants in P-Timing group showed a greater increase in startle from the ITI to the cue during the S condition.

We also found that participants in the U-Intensity condition had a different response to the cue than those in the P-Intensity condition and this finding was largely driven by group differences during the S condition. Taken together with previous reports on unpredictable timing, these two findings highlight the importance of predictability in aversive processing (Mineka and Kihlstrom, 1978; Seligman, 1968).

As discussed by Grillon et al. (2004), the safety-signal hypothesis may explain the anxiogenic effects of unpredictable timing. This theory asserts that cued (i.e., predictable) aversive events are preferred to non-cued (i.e., unpredictable) aversive events because the former connotes reliable safe periods that are indicated by the absence of danger cues (Seligman, 1968; Seligman and Binik, 1977). That is, animals prefer predictably timed over unpredictably timed shocks, not because of diminished aversiveness of cued shocks, but because the situation provides the animal with known shock-free periods during which the animal can reduce vigilance and thus relax (Seligman, 1968; Seligman and Meyer, 1970).

However, the safety-signal hypothesis can not address our findings for intensity. As the two Intensity groups were balanced on Timing (i.e., the variable which specifically manipulated the meaning of the cue), the cue (and in turn the safety signal) should have had the same meaning in both Intensity groups. However, during the shock condition there was a significant Intensity × Cue interaction, suggesting that the difference between the cue and ITI (i.e., potentiation to the cue) varied by whether the intensity of the shock was predictable.[1] This finding is also consistent with two animal studies (Fujii et al., 1994;Marlin et al., 1979). In both of these studies, cued shocks (i.e., shocks with predictable timing) were presented that were either of predictable or unpredictable intensity. Even though the shock-free (i.e., safety) periods were matched in both intensity conditions, animals exhibited more signs of anxiety in the unpredictable intensity condition in both studies. In short, these results suggest that the safety-signal hypothesis may not *always* address why unpredictability is anxiogenic (Badia et al, 1979).

An alternative hypothesis is the contextual anxiety hypothesis. This hypothesis proposes that aspects of the broad experimental context can become associated with anxiety and unpredictability plays a pivotal role in this process (Davis, 1998; Fanselow, 1980; 2010; Grillon, 2002; Grillon et al., 2004). The contextual fear hypothesis may address our results for Intensity. In participants in the U-Intensity condition, the cue may have become a contextual cue. That is, if the U-Intensity condition was more anxiogenic than the P-Intensity condition, it is possible that the cue became associated with the U-Intensity condition and increased participants startle response to the cue.

This interpretation of the Intensity results, however, is qualified by two points. First, the present study was not specifically designed to test the contextual fear hypothesis (or compare the contextual fear to the safety-signal hypothesis). Second, the two Intensity groups did not differ on self-reported anxiety ratings of the cue. However, Grillon and Morgan (1999) argue that self-report may not be as sensitive as startle at detecting contextual anxiety.

The contextual fear hypothesis may also explain the Timing × Intensity results. The Intensity manipulation increased startle for those in the P-Timing condition and not the U-Timing condition. Since this effect was for overall startle throughout the experiment and not specific to any condition (i.e., not the S, NS, etc.), it is possible that contextual anxiety was high for participants in any of the unpredictable groups. That is, to elevate the contextual anxiety of the experiment, it may be sufficient to instruct participants that *something* is unpredictable (e.g., either timing *or* intensity). This finding is also consistent with Berlyne's (1960) theory that the less information an individual has about important environmental

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[1] It is important to note that those in the P-Intensity group received more intense shocks than those in the U-Intensity group on average over the experiment. We felt that this was a necessary confound for several reasons. First, animal studies that have compared the effects of unpredictable vs. predictable intensity have matched the conditions on average intensity (Marlin et al., 1979; Fujii et al., 1994) suggesting that our effects for unpredictable intensity were not due to differences in average intensity. Second, we considered having the P-Intensity condition consist of predictable low shocks and predictable high shocks. While this would have matched the average intensity of shocks received by the P- and U-Intensity groups (at a level markedly less than highly annoying but not painful), it would have then been difficult to compare our results to previous studies that used a predictable intensity of highly annoying but not painful (e.g., Grillon et al., 2004). Additionally, if participants in the U-Intensity group were responding to the lower average intensity rather than to the unpredictability of the intensity, then compared to those in the P-Intensity group, one would expect them to report that the shocks were less aversive (which they did not) and to exhibit *lower* startle response during the shock condition not higher.

events (i.e., the more things are unpredictable), the more anxiogenic the situation will be (although see Badia et al., 1979 for a critical review of this theory). It will be important for future studies to extend this finding to other parameters of unpredictability (e.g., duration of aversive event, modality of aversive event, etc.) in order to determine whether unpredictable aversiveness, more broadly defined, is anxiogenic (D Amato and Safrajan, 1979; Imada and Nageiski, 1982). [2]

It is important to note that even though the Timing and Intensity findings were independent of each other (given the between-subjects nature of the design), the Timing findings yielded larger effect sizes than the Intensity findings. This suggests that a situation in which the organism does not know when (or if) an aversive event will occur may be a more aversive situation than one in which the organism does not know its intensity. This hypothesis is supported by the fact that the subjective anxiety and startle data corresponded for the Timing results, but not for the Intensity or Timing × Intensity results. Indeed, stronger emotional experiences (i.e., “strong situations;” Cooper and Withey, 2009; Mischel, 1977) are generally associated with greater coherence of subjective and physiological response systems (Mauss et al., 2005).

These findings also support a growing literature differentiating the aversive emotions of fear and anxiety (Barlow, 2000; Davis, 2006; Grillon, 2008). While both are aversive emotions, several researchers have identified predictability as one feature of aversive events that differentiates them (Barlow, 2000; Davis, 2006; Grillon, 2008a; Hamm and Weike, 2005). Fear has been defined as the emotion elicited during the classic fight, flight, or freeze response and is thus associated more with predictable danger. Anxiety has been defined as the emotion elicited when the perceived danger is less certain (or present) and is thus associated with unpredictable danger (Barlow, 2000; McNaughton and Corr, 2004; Smillie et al., 2006). Interestingly, the fear-anxiety distinction has been validated neurobiologically as the two emotions appear to be mediated by overlapping but separable neuroanatomical systems (Davis, 1998; 2006).

Our investigation was based on the paradigm developed by Grillon and colleagues (Grillon et al., 2004, 2008) in which P-Timing and U-Timing were within-subjects conditions. Because there may have been condition carry-over effects in the original design, we sought to compare P-Timing and U-Timing in a between-subjects design. The fact that our results for Timing were largely similar to those of Grillon and colleagues (also see Moberg and Curtin, 2009) suggests that previous results were not significantly influenced by carry-over effects. However, it is noteworthy that Grillon et al. (2004) reported elevated startle during the ITI of the P condition (when participants were safe) but we did not for startle (although we did for subjective anxiety).

In sum, the findings from the present study help elucidate two parameters of unpredictability that may contribute to aversive emotional responding. Our results suggest that an inability to predict the occurrence and/or the intensity of aversive events impacts aversive responding. Additionally, as discussed above, future studies are needed to examine other factors that can be unpredictable, such as the duration or modality (e.g., shock vs. aversive noise) of the aversive stimuli. Lastly, there are important treatment implications from our study. The efficacy of exposure treatments for anxiety disorders has received substantial support in the literature (Foa et al., 2005; Siev and Chambless, 2007) and our results support the

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[2] Interestingly, unpredictability may increase the positive experience of pleasant events (Bar-Anan et al., 2009). Thus, it may be that unpredictability enhances the intensity of the experience rather than being specific to anxiety (and possibly other negatively valence emotions).

recommendation that exposure to unpredictable stimuli may be important components of treatment (Barlow et al., 1989; Craske et al., 1995).

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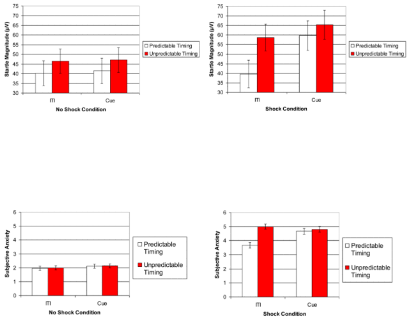

Figure 1.

Startle magnitude (μV; top) and subjective anxiety (arbitrary units [au]; bottom) during the Shock and No Shock condition at different levels of shock Timing (predictable vs. unpredictable). Error bars are standard errors.

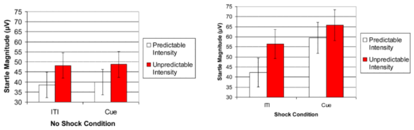

Figure 2.

Startle magnitude (μV) during the Shock and No Shock condition at different levels of shock Intensity (predictable vs. unpredictable). Error bars are standard errors.

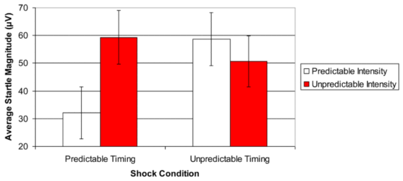

Figure 3.

Average startle amplitude (μV) in the Timing (Predictable vs. Unpredictable) × Intensity (Predictable vs. Unpredictable) groups. Error bars are standard errors.