# Personality, Punishment, and Procedural Learning: A Test of J. A. Gray's Anxiety Theory

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Effects of punishment and personality on a phylogenetically old form of knowledge acquisition, procedural learning, were studied to test J. A. Gray's (1970, 1987, 1991) theory of anxiety. Broad measures of personality (extraversion, E; neuroticism, N; and psychoticism, P) and specific measures of trait anxiety (Anx) and impulsivity (Imp) were taken. Punishment led to response invigoration, reducing reaction time latency, but this was not related to personality. A negative correlation of P and learning was observed in both punishment and control conditions. In support of Gray's theory, high Anx improved learning under punishment (and impaired learning under control), and low Anx improved learning under control (and impaired learning under punishment). These data are contrasted with H. J. Eysenck's (1967) arousal theory of personality. Results point to a new behavioral tool with which researchers can explore further the interaction of reinforcement, arousal, and personality.

The major biological models of personality (Eysenck, 1967; Gray, 1970, 1987, 1991) are characterized by an emphasis on (a) activation in phylogenetically old brain systems underlying the major dimensions of personality and (b) the importance of fundamental learning processes in the build up and maintenance of sociopsychiatric behaviors. The present experiment set out to explore personality-related influences on a phylogenetically old form of learning, namely, procedural learning, to test Gray's (1987, 1991) punishment-sensitivity theory of anxiety.

Gray's theory of anxiety postulates the existence of a *behavioral inhibition system* (Gray, 1976, 1982) that is charged with mediating responses to secondary aversive stimuli (i.e., punishment and the omission–termination of reward), extreme novelty, high-intensity stimuli, and innate fear stimuli (e.g., snakes, blood). On activation, the behavioral inhibition system produces outputs of (a) behavioral inhibition, (b) an increase in arousal, (c) heightened attention and information processing, and (d) the emotion of fear. Individual differences in sensitivity/activation of the behavioral inhibition system are postulated to give rise to trait anxiety (Anx).

The behavioral inhibition system may be contrasted with a second punishment system, the *fight–flight system* (Gray, 1987), which mediates responses to unconditioned (innate) aversive stimuli; this system produces the emotions of rage and panic, as distinct from fear, and is postulated to underpin the dimension of psychoticism (P; Eysenck & Eysenck, 1976). A third system, the *behavioral approach system* (Gray, 1987), mediates responses to secondary appetitive stimuli, namely conditioned rewarding stimuli and the omission–termination of punishment, and is postulated to give rise to impulsivity (Imp).

Building on H. J. Eysenck's factorial work on extraversion (E) and neuroticism (N; for a review, see Eysenck & Eysenck, 1985), Gray (1970) argued that Anx ranges from E−/N+ (Anx+) to E+/N− (Anx−), inclining more toward N than E. Orthogonal to Anx, Imp ranges from E+/N+ (Imp+) to E−/N− (Imp−), inclining more toward E than N. Gray's theory assumes that E and N are derivative factors of the more fundamental Anx and Imp: E reflects the balance of behavioral inhibition system and behavioral approach system strengths, and N, their combined strengths.

Gray's model postulates that anxious individuals should be especially sensitive to secondary aversive stimuli; in consequence, exposure to these stimuli should lead to increments in negative emotions and enhanced information processing, leading, among other things, to superior learning. A complementary prediction is made for impulsive individuals and secondary appetitive stimuli (in which case positive, not negative, emotions would be increased).

The prediction concerning Anx and strong emotional reactions to aversive stimuli has been confirmed. For example, psychophysiological indexes of emotional reactivity to aversive

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stimuli have shown that high Anx potentiates electromyographic (e.g., eyeblink) responses to acoustic probes in the presence of unpleasant slides (Cook, Hawk, Davis, & Stevenson, 1991; Corr, Wilson, et al., 1995).

However, Gray's prediction concerning anxious individuals' enhanced learning under punishment has been less frequently confirmed. Several studies have shown that introversion predicts reactions to punishment (e.g., Boddy, Carver, & Rowley, 1986; Gupta, 1976, 1990; Gupta & Nagpal, 1978; Gupta & Shukla, 1989; McCord & Wakefield, 1981; Nagpal & Gupta, 1979), but attempts to relate specific measures of Anx to punishment-enhanced learning have met with little success (e.g., Gorenstein & Newman, 1980; Newman, 1987; Zinbarg & Revelle, 1989). In our own laboratory, we (Corr, Pickering, & Gray, 1995a) found that passive avoidance behavior (that had been divested of its associative components by prior conditioned stimulus–unconditioned stimulus conditioning) was predicted by low Imp and not high Anx.

Gray's theory was built on behavioral and brain studies in lower animals, principally the rat. For this reason, it may be assumed that the core behavioral responses, assumed by Gray to be mediated by the behavioral inhibition system, behavioral approach system, and fight–flight system are based in phylogenetically old and relatively primitive learning systems; in current terminology, in *procedural* learning, as distinct from *declarative* learning. Therefore, it seems reasonable to assume that, in human beings, Gray's emotion systems would be most influential in phylogenetically old forms of learning.

Procedural learning occurs without conscious effort or awareness of the to-be-learned material (Hartmann, Knopman, & Nissen, 1989; Lewicki, Czyzewska, & Hoffman, 1987; Reber, 1989); it encodes rules (Nosofsky, Clark, & Shin, 1989) rather than instances or events (Brooks, 1978). The acquisition of procedural information is assessed by such tasks as mirror reading, pursuit rotor, and sequence reaction time (RT) tasks. In contrast, declarative learning entails conscious processing of the to-be-learned material (Anderson, 1982), leading to knowledge that is available to conscious awareness and processing. Declarative learning is measured by recall and recognition memory. These two types of learning–memory processes are also known as *implicit* and *explicit*, respectively (Graf & Schacter, 1985).

The contention that Gray's theory might be more adequately tested at the level of procedural learning receives support from the dissociation of procedural and declarative processes (for a review, see Feldman, Kerr, & Streissguth, 1995). For example, amnesics are impaired on declarative but not procedural processes (N. J. Cohen & Squire, 1980; Corkin, 1968; Nissen & Bullemer, 1987; Nissen, Willingham, & Hartman, 1989; Squire, 1986). Declarative–procedural dissociations have been observed in individuals with memory disorders resulting from Alzheimer's disease (Deweer et al., 1994; Knopman & Nissen, 1987; Sabe, Jason, Juejati, Leiguarda, & Starkstein, 1995); in healthy volunteers following injection of scopolamine, an anticholinergic drug that produces temporary amnesia (Nissen, Knopman, & Schacter, 1987); and in psychotic patients (Schmand, Brand, & Kuipers, 1992). Dissociations can also be experimentally produced, for example, by manipulating type of processing (Jacoby & Dallas, 1981) or modality (Roediger & Blaxton, 1987), and procedural memory shows less forgetting than declarative memory (Jacoby & Dallas, 1981; Tulving, Schacter, & Stark, 1982). In addition, declarative and procedural systems are not neurologically identical (Squire, 1986).

Few studies have examined the effects of personality processes on procedural learning, despite the fact that, because of their antiquity, nondeclarative systems of learning seem ideally suited to testing biologically based personality models. To some extent, such studies have been discouraged by the widely held belief in the "robustness" of procedural learning measures, which, "owing to their phylogenetic antiquity, will show less individual-to-individual variation than comparable explicit [learning] processes" (Reber, Walkenfeld, & Hernstadt, 1991, p. 894).

However, clinical research has shown clear dissociations between implicit and explicit retrieval measures of Anx effects: Anxious individuals show superior implicit retrieval of threat-related material (e.g., Amir, McNally, Riemann, & Clements, 1996; Harris, Adams, Menzies, & Hayes, 1995; MacLeod & McLaughlin, 1995; McNally, 1995), indicating that the automatic processing of such punishment-related stimuli is enhanced in anxious individuals. However, it is not clear whether these results reflect an influence of Anx on the *learning* or *retrieval* of threat-related stimuli.

Procedural learning also offers a valuable tool with which to contrast Gray's punishment theory of Anx and Eysenck's (1967) arousal theory of extraversion. Eysenck's theory predicts that, on the basis of individual differences in cortical arousal/arousability, introverts should show optimal performance under low-arousing conditions and suboptimal performance under highly arousing conditions; extraverts should show suboptimal performance under low-arousing conditions and optimal performance under highly arousing conditions. Assuming that punishment is arousing, Eysenck's theory predicts that introverts should learn better than extraverts under control (low-arousal) conditions, but under punishment (high-arousal) conditions, introverts' learning should decline relative to extraverts'. In marked contrast, Gray's theory predicts enhanced learning by introverts under punishing, high-arousal conditions.

A powerful test of Gray's punishment predictions is afforded by results that show that, in the absence of reinforcement manipulations, Eysenck's arousal-based predictions are confirmed. Corr, Pickering, and Gray (1995b) reported an interaction of (caffeine-induced) arousal and extraversion, the pattern of which agreed with Eysenck's theory. In addition, Corr and Kumari (1997) found that haloperidol (a drug that has sedative properties) also interacted with extraversion, producing effects opposite to those of caffeine. If Eysenck-type arousal effects are found only under reinforcement-neutral conditions, with reinforcement overriding this default arousal effect (as assumed by Gray's theory), then the Arousal × Extraversion effects previously reported should be replaced by a Gray-type Punishment × Anx interaction, which, if consistent with Gray's predicted pattern of effects, would be highly inconsistent with Eysenck's expected pattern.

The procedural learning task used in this experiment consists of a long series of reactions to a target that moves between four locations on a computer monitor. Some of these target movements are random, whereas others follow specific patterns and are thus predictable. Participants point to the target with a wand that activates a touch-sensitive screen; the target then moves to another location, and participants continue to follow the target as it moves among four locations. As shown by Lewicki, Hill, and Bizot (1988), there is a selective decline in RTs to predictable targets relative to RTs to random targets; this difference reflects procedural learning. To the extent that reactions to predictable targets are influenced by personality and reinforcement, it should be possible to test Gray's predictions of greater learning under punishment for highly anxious individuals.

## Method

### *Participants*

We recruited 100 volunteers by means of advertisements placed in local newspapers; 50 were men (mean age = 27.73 years, $SD = 8.31$), and 50 were women (mean age = 25.69 years, $SD = 6.66$). Participants received £5.00 payment in exchange for participating.

### *Design*

We used an independent groups design in which participants were (quasi-) randomly allocated to either a control or a punishment condition, with the requirement that (a) equal numbers of men and women were assigned to each condition ($ns = 25$) and (b) the time of day of testing did not become a systematic source of error. Participants' age was distributed equally over control ($M = 26.52$, $SD = 5.75$) and punishment ($M = 27.52$, $SD = 9.22$) conditions ($F < 1$).

### *Personality Questionnaires*

A broad range of personality measures was taken to sample the factor space hypothesized by both Eysenck and Gray to encompass higher order personality structure. This strategy also precluded the possibility that any observed personality might have been biased by selection criteria.

Extraversion (E), neuroticism (N), psychoticism (P), and lie (L) were measured by the Eysenck Personality Questionnaire (Eysenck & Eysenck, 1975); Imp was measured by the Impulsiveness (IVE) Questionnaire (which forms a part of the Eysenck Personality Scales; Eysenck & Eysenck, 1991). The State–Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983) provided the measure of trait Anx. These questionnaires were scored after the experiment was completed.

### *Learning Task*

The task was a modified version (Corr, 1994; Corr, Pickering, et al., 1995b) of Lewicki et al.'s (1988) task. The task comprised serial RTs, consisting of participants touching a target (an asterisk) that appeared in one of four locations on a computer monitor; once the target was touched by a participant, it moved to a different location. Participants followed the target around the screen, touching it each time it moved to a new location.

The screen background was black, and two intersecting lines, which separated the screen into four equally sized quadrants, were white, as was the moving target. The target appeared centrally in the quadrants. The movement of the target was initiated by the participant touching the screen with a wand. The target area was defined as a 2-cm radius around the target. The target moved to another quadrant only if it had been "touched" with the wand. The movement time of the target was (almost) instantaneous.

### *Stimuli*

The whole task was composed of 15 separate blocks, each of which contained 48 subblocks. Each subblock contained five target movements. The five target movements of each subblock were either random (Trials 1 and 2) or predictable (Trials 4 and 5). (The third target movement of each five-trial sequence was excluded; see Perruchet, Gallego, & Savy, 1990).

The only exception to the above rules was Block 14, in which all target movements were random (this was included to determine whether the random–predictable trial type designation was responsible for the observed procedural learning).

Therefore, each block contained 240 target movements, grouped into 48 subblocks of 5 target movements. All 48 subblocks were randomly presented (randomized for each participant) with the restriction that: (a) the first trial was not predicted from the preceding trial (i.e., the 5th target movement of the immediately preceding five-trial sequence) and (b) the target never remained at the same location on two trials in succession.

The movement of each target was accompanied by a musical note unique to each of the five trials; the sequence of notes was chosen to resemble the well-known theme of Steven Spielberg's film *Close Encounters of the Third Kind* (Phillips, Phillips, & Spielberg, 1977). This tune helped to demarcate the subblocks of trials, although the significance of the subblocks was never explained to the participants.

### *Rules Governing Predictable and Random Trials*

*Predictable target movements (Trials 4 and 5).* The following rules applied to predictable target movements: (a) If the preceding target movement was horizontal, then the next target movement would be vertical; (b) if the preceding target movement was vertical, then the next target movement would be diagonal; and (c) if the preceding target movement was diagonal, then the next target movement would be horizontal. These rules determined a maximum of 12 different five-trial sequences.[1] Each of these was repeated four times (total = 48).

*Random target movements (Trials 1 and 2).* These trials violated the rules for the predictable trials and were therefore strictly quasi-random.

### *Data Reduction*

For each block, the mean RT for each of the 5 trials was recorded (i.e., the mean of 48 trials). These summary data permitted the calculation of RTs on random and predictable trials; the difference between these RTs represented procedural learning. RTs that exceeded 1.0 s were excluded (RTs rarely exceeded 0.5 s, and when they did it was because of error responses, e.g., accidental dropping of the wand).

### *Manipulation of Punishment*

*Punishment criteria.* The schedule of punishment was based on a probabilistic rule, which ensured a constant rate of punishment over the blocks of the task. Punishment was delivered when RTs for predictable trials (3–5) were all individually slower than corresponding RTs on the immediately preceding subblock, if RTs on random trials (1–2) were not also slower.[2]

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[1] The twelve five-trial sequences were as follows (numbers refer to the position of the target in one of four quadrants: 1 = upper left; 2 = upper right; 3 = lower left; 4 = lower right): 1, 2, 4, 1, 2; 1, 4, 3, 1, 4; 1, 3, 2, 1, 3; 2, 1, 3, 2, 1; 2, 4, 1, 2, 4; 2, 3, 4, 2, 3; 4, 1, 2, 4, 1; 4, 2, 3, 4, 2; 4, 3, 1, 4, 3; 3, 1, 4, 3, 1; 3, 2, 1, 3, 2; 3, 4, 2, 3, 4.

[2] These criteria were initially designed to produce contingent reinforcement. However, the nonsalient nature of the task led to de facto noncontingent reinforcement (see Discussion): Contingent versus yoked reinforcement groups' learning did not differ (Corr, 1994). Therefore, these criteria are important only in so far as they ensured a number of punishers over the 15 blocks of the task.

One-way analysis of variance (ANOVA) confirmed the equal distribution of punishment ($M = 4.10$, $SD = 0.57$) over the 15 blocks of the task, $F(14, 686) = 1.27$, $p > .05$. (The mean number of punishers delivered did not significantly correlate with any of the personality measures, thus ruling out any subtle personality-related contingent effect of punishment.)

*Delivery of punishment.* Punishment was manipulated by the following three different means: (a) monetary decrements (5 pence units), which were presented on screen immediately after behavior meeting the above criteria for punishment; (b) messages appearing on the screen during the interblock intervals; and (c) the actual taking of coins during interblock intervals.

Participants in the punishment condition received £5.00 at the start of the experiment. They were told that they might lose some of this money if their performance fell below expectation (see *Instructions*). Responses meeting the punishment criteria led to 5 pence decrements; this outcome was signaled immediately by a computer-generated auditory tone of short (500 ms) duration. The sum of money remaining was shown continuously in the center of the screen.

For the interblock interval, a graded system of punishment messages was used (similar to Boddy et al., 1986). The number of punishers per block was associated with one of five different flashing messages: 1–2, "Bad Luck!"; 3–4, "Bad Score!"; 5–6, "Very Bad Score!"; 7+, "Terrible Score!".

The temporal sequence of messages presented during the 30-s interblock interval was as follows: (a) "LOOK HERE," flashing (0–5 s); (b) one of the above messages (flashing for 6–25 s) and "YOU HAVE LOST X PENCE/YOUR SCORE SO FAR IS Y% WORSE THAN EXPECTED" [where Y randomly fluctuated between 9 and 11]; and (c) "TRY TO BE FAST AND ACCURATE/YOU HAVE £X. XX/TOUCH GO TO CONTINUE" (flashing for 27–30 s; X.XX represented the sum of money remaining).

During the interblock interval, the number of 5 pence coins lost during the block was taken from participants (coins were removed from a container situated next to the computer monitor). The taking of coins was performed in a conspicuous manner to emphasize the monetary consequences of the screen-presented punishment.

In the control condition, participants received no feedback on their performance.

## Instructions

The following instructions were given for each of the pretest practice session and the two test conditions.

*Practice.* "As you can see, the screen is divided into quadrants. A target (*) will move between these quadrants and your task is to touch each target with the wand in the manner already described to you. A practice period follows to familiarize you with the task. *Remember that your response should be fast and accurate.* Please touch 'GO' to start."

*Control.* "During the next section of the computer task, you will be presented with the same sequence of targets. However, this time the computer will calculate how fast and accurate you are. Please touch 'GO' to start."

*Punishment.* "During the next section of the computer task, you will be presented with the same sequence of targets. However, this time the computer will calculate how fast and accurate you are, and if your performance begins to get worse you will lose 5 pence. Your losses will be immediately displayed in the center of the screen and subtracted from the initial starting figure of £5.00. At regular intervals the computer will display a message informing you of how you are doing; and the experimenter will then take from you the amount of money you have lost during that segment of the task. Please read this message carefully and follow the instructions given as you will be asked questions about this later. The amount of money you have at the end of the experiment will be yours to keep. Remember the amount of money you lose depends entirely on your speed and accuracy. Please touch 'GO' to start."

## Equipment

The task was controlled by an ATARI ST1040 microcomputer, which recorded all responses. The stimuli were presented on an ATARI SC1224 monitor, and a Microvitec touchtec 501 touch screen was fitted over the front of the monitor to register responses. The wand used by participants was a 12-in. long, thin perspex tube. The wand did not have to touch the screen for a response to be registered; rather, the wand had to break a matrix of infrared beams of light that crisscrossed the touch screen. The spatial position of the target position on the touch screen corresponded exactly with the target position on the computer monitor. We provided an elbow rest for the comfort of participants and for the reduction of fatigue due to repetitive arm and hand movements.

## Procedure

Participants were told that they would be required to perform a simple computerized learning task in which they might either win or lose money (this latter instruction served to strengthen the effect of punishment). Participants then completed a consent form describing the nature of the experiment as well as personality questionnaires. Before the practice session, we demonstrated to participants the use of the wand and touch screen and then gave the written practice instructions.

After the practice session, we told participants in the punishment condition that they would receive £5.00 for coming to the experiment but that they may lose some of this money (therefore, the money they lost belonged to them at the beginning of the experiment; the money was placed in a container next to the computer).

Each block was demarcated by a 30-s rest period, and the next block was initiated by the participant, prompted by a message appearing on the screen to "press GO to continue." The task took approximately 45 min.

Testing took place in a sound-attenuated experimental cubicle. The experiment was conducted between 9 a.m. and 6 p.m. The ethical considerations were assessed by the Ethics Committee of the Institute of Psychiatry at the University of London.

# Results

Table 1 shows descriptive statistics for personality measures in control and punishment conditions; Table 2, the intercorrelation of the personality variables.

## Task Analysis

Before exploring the effects of personality on procedural learning, we conducted an analysis of the task. We performed a three-way ANOVA, with repeated measures on (a) RTs over 14 Blocks (excluding the completely random 14th block), (b) Trial Type (representing the difference between random and predictable trials, i.e., procedural learning), and (c) between-subject Reinforcement (control vs. punishment).

*RTs over blocks.* A main effect of Reinforcement, $F(1, 98) = 5.55$, $p < .05$, revealed that, relative to control and irrespective of Trial Type, punishment sped up RTs (Figure 1). A main effect of Blocks, $F(13, 1274) = 47.70$, $p < .001$, reflected a gradual decline in RTs over the course of the task. The Reinforcement × Blocks interaction was not significant ($F < 1$), indicating that the shape of the RT curve was not affected by Reinforcement.

*Trial Type.* A main effect of Trial Type, $F(1, 98) = 222.89$, $p < .001$, confirmed the existence of procedural learning over the whole task. A Trial Type × Blocks interaction, $F(13, 1274) = 22.83$, $p < .001$, showed that procedural learning gradually increased over the blocks of the task (Figure 1). Neither Rein-

Table 1
*Means, Standard Deviations, and Ranges for Personality Measures Taken at the Beginning of the Experiment in the Control and Punishment Conditions*

| | Control | | | Punishment | | |
|---|---|---|---|---|---|---|
| Measure | *M* | *SD* | Range | *M* | *SD* | Range |
| EPQ–E | 12.38 | 4.81 | 1–21 | 13.48 | 4.62 | 1–21 |
| EPQ–N | 13.02 | 5.34 | 2–23 | 11.82 | 4.56 | 1–21 |
| EPQ–P | 4.98 | 3.31 | 0–15 | 6.28 | 3.73 | 0–20 |
| EPQ–L | 5.08 | 3.59 | 0–14 | 5.44 | 4.17 | 0–19 |
| EPS–Imp | 8.71 | 4.88 | 1–18 | 8.20 | 4.53 | 0–18 |
| STAI–Anx | 41.18 | 10.21 | 23–66 | 42.24 | 7.61 | 26–61 |

*Note.* EPQ = Eysenck Personality Questionnaire (Eysenck & Eysenck, 1975); E = extraversion; N = neuroticisim; P = psychoticism; L = lie; EPS = Eysenck Personality Scales (Eysenck & Eysenck, 1991); Imp = impulsivity; STAI = State–Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983); Anx = anxiety.

forcement × Trial Type nor Reinforcement × Trial Type × Blocks interactions were significant, indicating that learning was not differentially affected by control and punishment (but see below for moderating role of personality).

### *Trial Type Validation*

In Block 14 all trials were random; therefore, procedural learning should have been abolished. Confirming this expectation, there was no difference between random (*M* = 540, *SEM* = 4) and predictable (*M* = 539, *SEM* = 4) trials in Block 14, $t(99) = 0.57$, *ns*, indicating that elimination of trials designated as predictable abolished the learning effect. This finding contrasts with the learning effect observed on either side of the 14th block, in Block 13 (Random: *M* = 546, *SEM* = 4; Predictable: *M* = 508, *SEM* = 5), $t(99) = 12.27$, $p < .001$, and in Block 15 (Random: *M* = 545, *SEM* = 4; Predictable: *M* = 507, *SEM* = 5), $t(99) = 13.48$, $p < .001$.

These data attest to the validity of the predictable–random targets, operationalized as procedural learning (Trial Type). To maximize the effects of punishment, we used performance in the last block of the task, Block 15, to represent the asymptotic learning.

### *Personality Effects*

A regression approach was adopted to uncover personality and reinforcement effects on asymptotic learning. This multivariate technique is preferable to taking median splits because it preserves statistical power (J. Cohen, 1968) and reduces statistical artifacts (Bissonnette, Ickes, Bernstein, & Knowles, 1990); in addition, the flexibility of regression analyses allows an optimal set of predictors to be identified.

Multiple regression analyses included the following variables: (a) Reinforcement and all personality variables, and (b) two-way interactions between Reinforcement and each personality variable. (The control condition was coded −1 and the punishment condition +1.) We used a stepwise entry of variables and set probability-to-enter at .10. We centered variables before we computed interaction cross-products (Aiken & West, 1991); these cross-products are comparable to ANOVA-type interactions and may be interpreted accordingly.

*Random trial RTs.* First, we undertook a multiple regression analysis of random trials to discount the possibility that any observed personality effects on learning might have been artifacts of general RT rather than specific responses to predictable targets. Only Reinforcement was significant, $F(1, 96) = 5.06$, $p < 05$ ($\beta = -298$); RTs were faster under punishment (*M* = 535, *SEM* = 5) than under control (*M* = 555, *SEM* = 7) conditions. The same effect was found for responses to predictable trials, $F(1, 96) = 3.32$, $p = .07$ ($\beta = -18$); again, RTs were faster under punishment (*M* = 497, *SEM* = 7) than under control (*M* = 518, *SEM* = 8) conditions (see Figure 1).

These results indicate that punishment had a general response invigoration effect, increasing the speed of all RTs. No effects of personality, or Reinforcement × Personality variables, were found, indicating that any effect of personality on learning could not be accounted for by this effect of punishment on general response speed.

*Asymptotic learning.* The overall multiple regression model was significant, $F(2, 95) = 6.74$, $p < .01$ ($R = .35$). This model comprised: (a) a main effect of P ($\beta = -.25, p < .01$) and (b) a Reinforcement × Anx interaction ($\beta = .25$, $p < .01$). As shown in Figure 2, under control, Anx was negatively correlated with learning ($\beta = -.28$), whereas under punishment it was positively correlated ($\beta = .22$).

It should be noted that this Reinforcement × Anx effect was not conditional on inclusion of P in the model; nor was P conditional on the Reinforcement × Anx interaction term. A conventional two-way ANOVA, with median splits on Anx, also revealed a significant Reinforcement × Anx interaction, $F(1, 93) = 4.68$, $p < 05$ (plotted in Figure 2), and the same was true of the main effect of P, $F(1, 86) = 4.38$, $p < 05$.

Table 2
*Intercorrelation of Personality Variables (Control, Upper Diagonal; Punishment, Lower Diagonal)*

| Variable | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1. Extraversion | — | −.198 | −.198 | .034 | .169 | −.408* |
| 2. Neuroticism | .218 | — | .485* | −.150 | −.019 | .611* |
| 3. Psychoticism | −.203 | .134 | — | −.445* | .272 | .164 |
| 4. Lie | .166 | −.168 | .180 | — | −.101 | −.024 |
| 5. Impulsivity | .433* | .276 | .108 | .209 | — | −.047 |
| 6. Anxiety | −.119 | .618* | .161 | −.207 | .061 | — |

*$p < .01$, two-tailed.

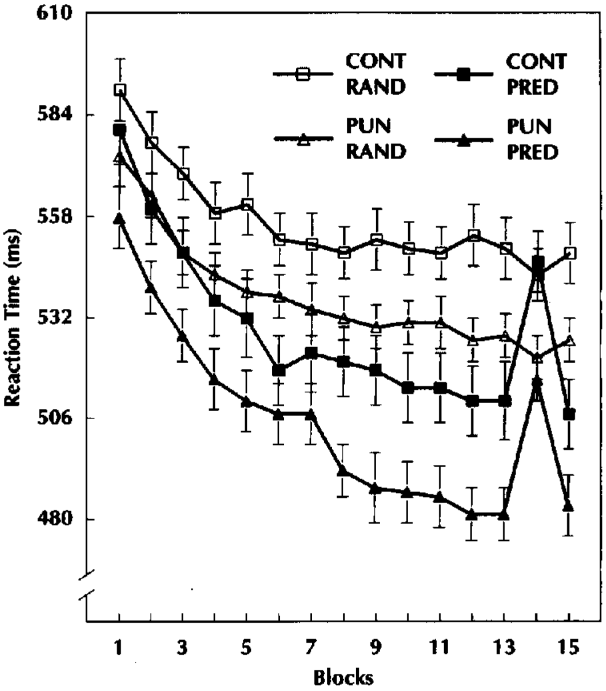

*Figure 1.* Mean reaction times (ms; ±1 *SEM*) to random (RAND) and predictable (PRED) targets in control (CONT) and punishment (PUN) conditions over the 15 blocks of the task.

## Discussion

The results provide support both for the general expectation that punishment and personality would affect procedural learning and for Gray's specific hypothesis that the effects of punishment will be moderated by Anx. The data revealed that high Anx impaired learning under control but facilitated it under punishment and that the reverse pattern of effects was true for low Anx (Figure 2). Taken together, these effects indicate that anxious individuals are at a double disadvantage: Their superior punishment learning is compounded by their poor learning under neutral conditions. The crossover pattern of Anx and reinforcement effects explains the failure to find a main effect of punishment on learning.

The task demanded rapid responding and prevented behavioral inhibition; yet highly anxious individuals still appeared to benefit from punishment-initiated information processing. This finding suggests that activation of the behavioral inhibition system does not have to produce behavioral inhibition for its information-gathering functions to become activated. The behavioral inhibition system concept may thus be relevant to types of learning outside prototypical behavioral inhibition system paradigms, namely passive avoidance and extinction.

The pattern of moderating effects of Anx on punishment is not consistent with Eysenck's arousal-based theory of personality. Specifically, anxious (putatively highly aroused) individuals did not show any effect of (punishment-induced) overarousal: Relative to the low-arousal (control) condition, anxious individuals showed an improvement in performance under the high-arousal (punishment) condition. This effect is diagonally opposed to Eysenck's predictions. In both control ($r = .20$, *ns*) and punishment ($r = .08$, *ns*) conditions, high extraversion tended to be associated with higher levels of learning, further discounting an arousal-based interpretation of punishment effects. However, it is possible that the interaction of (caffeine-induced) arousal and extraversion (Corr, Pickering, et al., 1995b) is independent of Punishment × Anx effects. This intriguing possibility could be tested by a factorial combination of arousal, punishment, and personality. If arousal–personality and punishment–personality effects are independent, then this would suggest that Eysenck's and Gray's theories relate to separate causal personality processes and thus are complementary.

Gray's model predicts that reinforcement should lead to nonspecific arousal, which is hypothesized to increase the intensity of ongoing behavior. This indeed was found for responses to both random and predictable targets: Punishment led to a speeding up of RT. However, personality did not moderate this effect, indicating that the Anx and psychoticism effects on learning were independent of this response invigoration effect. This finding might indicate that the response invigoration induced by punishment is different than the arousing effects of caffeine, which are moderated by personality (Corr, Pickering, et al., 1995b).

The deleterious effect of psychoticism on learning is consistent with previous reports (e.g., Beyts, Frcka, Martin, & Levey, 1983) that show a general failure of learning in high-psychoticism individuals. Although psychoticism did not specifically moderate the effects of punishment, it did impair learning under punishment—a finding that is consistent with the view that high-psychoticism (or psychopathic; Eysenck & Eysenck, 1991)

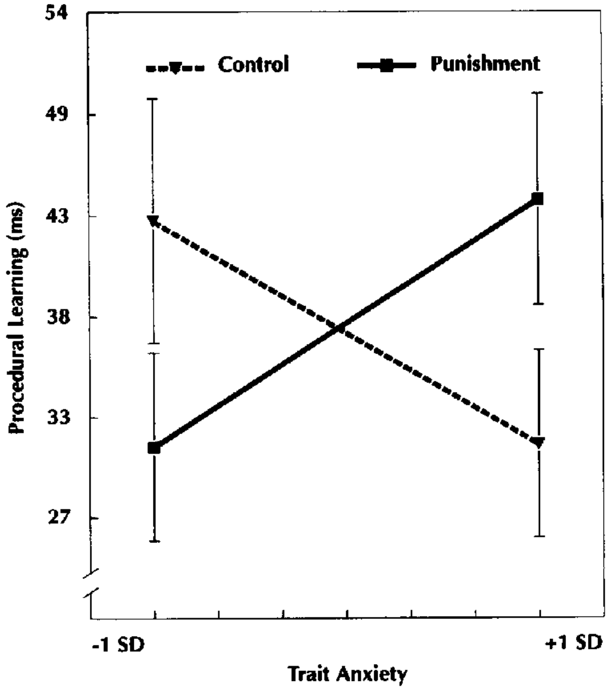

*Figure 2.* Mean procedural learning (ms; ±1 *SEM*) showing low and high trait anxiety (±1 *SD*) groups in control and punishment conditions.

individuals have weak responses to punishing stimuli and, as a consequence, are undersocialized.

The nature of the procedural information contained in the distinction between predictable and random targets is open to debate. It is probable that participants learn not the deep underlying structure of the task (cf. Lewicki et al., 1988) but rather the differential distribution of frequency information that is contained in the predictable or random targets (cf. Perruchet et al., 1990). The frequency hypothesis of procedural learning suggests that automatic learning is similar to animal learning paradigms (e.g., classical conditioning), which entail the learning of stimulus covariation frequencies. Seen in this light, procedural learning may provide a close human analogue of the learning processes of lower animals that formed the basis of Gray's reinforcement theory of personality.

The predictable stimuli were nonsalient, and participants' informal comments confirmed this view. In support of these informal comments, Corr (1994) found that (a) participants' perceived degree of knowledge of these stimuli, and their confidence in expressing the procedural rule, was very low; (b) when participants were asked to generate on paper exemplar trial sequences of the procedural rule, their performance was not greater than chance; and (c) participants were unable to generate, at above chance levels, the next correct target from partially completed sequences shown on the computer monitor, although they were able to accurately recognize correct and incorrect target sequences shown on the computer screen.

The nonsalient nature of the stimuli used in this experiment may have enhanced the effects of punishment: Not being able to predict or control aversive events is itself punishing. In addition, the constant rate of punishment, which did not decline with the accumulation of learning, may also be assumed to have added to the aversiveness of the punishment condition. These aspects of the design worked toward ensuring that the punishment condition was de facto aversive.

The research strategy of the present experiment could be extended to test Gray's predictions concerning the role of impulsivity in reward-mediated learning. However, preliminary research in our laboratory suggests that the manipulation of reward may be more difficult than that of punishment. First, a constant rate of reward, that is, one that does not increase with learning, may lead to frustration and therefore serve as a form of aversive stimulation. Second, the nonsalient nature of predictable and random stimuli may attenuate the feedback link between reward and responses and may thereby weaken the appetitive value of reward. For these reasons, it may be preferable to reward not specific sets of responses but overall performance over the 15 blocks of the task. Assuming that reward facilitates procedural learning, Gray's theory clearly predicts that highly impulsive individuals should show superior learning under de facto rewarding conditions.

In conclusion, the present results show the importance of both punishment and the major dimensions of personality on procedural learning. Anx moderated the effects of punishment in accordance with Gray's theory of Anx, supporting a major, but infrequently confirmed, tenet of Gray's theory that activation of the behavioral inhibition system by secondary aversive stimuli leads to enhanced learning in anxious individuals.

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