Available online at www.sciencedirect.com
SCIENCE DIRECT®

Neuroscience and Biobehavioral Reviews 28 (2004) 317–332

NEUROSCIENCE AND BIOBEHAVIORAL REVIEWS

www.elsevier.com/locate/neubiorev

Review

Reinforcement sensitivity theory and personality

Philip J. Corr

Department of Psychology, University of Wales Swansea, Wales, UK

Abstract

A fully fledged neuroscience of personality is beginning to emerge, shaped and guided in large measure by the seminal work of Jeffrey A. Gray over a period of 40 years. In this Festschrift, I trace the theoretical development of Gray's approach—now known as *Reinforcement Sensitivity Theory* (RST)—out of the Eysenckian tradition to its most recent articulation. Experimental attempts to test RST are reviewed and the theoretical problems raised by this literature discussed. Also presented are data relating to a recent clarification of RST, viz. the *joint subsystems hypothesis*, which postulates a fundamental interdependence of appetitive and aversive systems in the typical human laboratory. The value of Gray's general approach to building behavioural theories on the bases of both the conceptual nervous system and the real nervous system is validated in personality, which has long been thought a philosophical mystery rather than a standard problem to be tackled by scientific method.

Keywords: Behavioural inhibition; Behavioural approach; Fight–flight–freeze system; Personality; Motivation; Emotion; Reinforcement sensitivity theory; Joint subsystems hypothesis; Arousal; Extraversion; Neuroticism

Contents

E-mail address: philip.corr@btopenworld.com.

0149-7634/$ - see front matter
doi:10.1016/j.neubiorev.2004.01.005

1. Introduction

Personality has long been the Cinderella of psychology: its scientific potential thwarted by psychoanalysis, social constructivism and statistical indeterminism, and neglected by experimental (cognitive) psychology. This dismal state of affairs has finally changed with the emergence of a rapidly developing neuroscience of personality [1], a shift in scientific fortune made possible, in large part, by the seminal work of Jeffrey A. Gray.

Another article in this Festschrift [2] outlines Gray's neuroscience of fear and anxiety; here I focus on those aspects of his general theory that are applied specifically in the human experimental laboratory. In particular, I summarise the theoretical development of Gray's neuropsychological theory of personality—now known as *Reinforcement Sensitivity Theory* (RST) [3]—outlining its theoretical antecedents and its development over the years, culminating in the most recent formulation [4]. Human experimental evidence for RST and the problems highlighted by these data, are discussed; and a recent clarification, which emphasizes the joint effects of the fundamental emotion systems, is presented in the light of empirical evidence.

2. Reinforcement sensitivity theory: background

The origins of RST are to be found in *Pavlov's Typology* [5] (also submitted as part of Gray's PhD thesis in the same year). This work was a literal and conceptual translation of Pavlovian ideas of personality prevalent in the Soviet Union at that time: it linked ideas of excitation–inhibition with Western concepts of arousal and activation [6]—the role of arousal and activation were later to play a key role in Hans Eysenck's highly influential biological theory of personality [7]. Importantly, this book brought to the attention of researchers Pavlov's approach to individual differences, viz. that a rigorous analysis of behaviour can be used to understand personality. In later years, Gray would relate this conceptual analysis of learning and reinforcement to the known real nervous system of reward and punishment mechanisms—this general approach, of course, has much in common with Donald Hebb's [8,9] neuropsychology. The importance of a biological—more precisely, a physiological—theory of personality was adumbrated by Gray [10]:

> In the long run, any account of behaviour which does not agree with the knowledge of the neuro-endocrine systems…*must be wrong.* (p. 373)

2.1. Hans Eysenck's biological theory of personality

To understand RST, it is necessary first to appreciate Hans Eysenck's biological (more accurately, biosocial) model of personality. From the early 1940s [11] until his death in 1997 [12], Eysenck pursued a programme of research devoted: (a) to the *description* of the major dimensions of personality; and (b) to the development of biologically based *causal* theories to account for these dimensions. Eysenck developed the most influential biological model of personality, and his approach laid the necessary foundations for the realisation of a neuroscience of personality. In particular, his approach gave rise to a wealth of empirical research and, less importantly, a belief that the apparent mysteries of human personality were, after all, little more than just another difficult problem to be solved by scientific method. Much work in RST has attempted experimentally to contrast Eysenck's arousal and Gray's reinforcement-based theories (for a review see Refs. [13,14]).

Eysenck's arousal theory of Extraversion (E) [7] postulated that introverts and extraverts differ with respect to the sensitivity of their cortical arousal system in consequence of differences in response thresholds of their ascending reticular activating system (ARAS). According to this theory, compared with extraverts, introverts have lower response thresholds and thus higher cortical arousal. In general, introverts are more cortically aroused and more arousable when faced with sensory stimulation. However, the relationship between arousal-induction and actual arousal is subject to the moderating influence of transmarginal inhibition (TMI: a protective mechanism that breaks the link between increasing stimuli intensity and behaviour at high intensity levels): under low stimulation (e.g. quiet or placebo), introverts should be more aroused/arousable than extraverts, but under high stimulation (e.g. noise or caffeine), they should experience over-arousal which, with the evocation of TMI, can lead to lower increments in arousal as compared with extraverts; conversely, extraverts under low stimulation should show low arousal/arousability, but under high stimulation, they should show higher increments in arousal. A second dimension, Neuroticism (N), is related to activation of the limbic system and emotional instability (for review see Ref. [15]).

2.2. Gray's (1970) psychophysiology of introversion–extraversion

The official birth date of RST was 1970, with the publication of an alternative psychophysiological theory of introversion–extraversion [16]. This publication proposed changes: (a) to the rotation of Eysenck's E and N dimensions; and (b) to their underlying neurophysiological bases. Gray argued that E and N should be rotated by approximately 30° to form the more casually efficient axes: Punishment Sensitivity, reflecting Anxiety (Anx); and Reward Sensitivity, reflecting Impulsivity (Imp) (see Fig. 1; also see Ref. [17]).[1]

[1] For simplicity, a 45° rotation is often depicted, but as shown in Fig. 1, punishment sensitivity is closer to N than E.

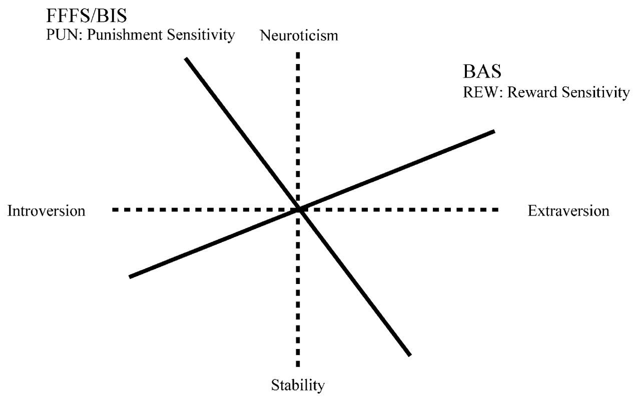

Fig. 1. Position in factor space of the fundamental FFFS/BIS (PUN, punishment sensitivity) and BAS (REW, reward sensitivity) (unbroken lines) and the emergent *surface expressions* of these sensitivities, viz. Extraversion (E) and Neuroticism (N) (broken lines). In the revised theory, a clear distinction exists between fear (FFFS) and anxiety (BIS), and separate personality factors may relate to these systems; however, for the present exposition, these two systems are considered to reflect a common dimension of punishment sensitivity.

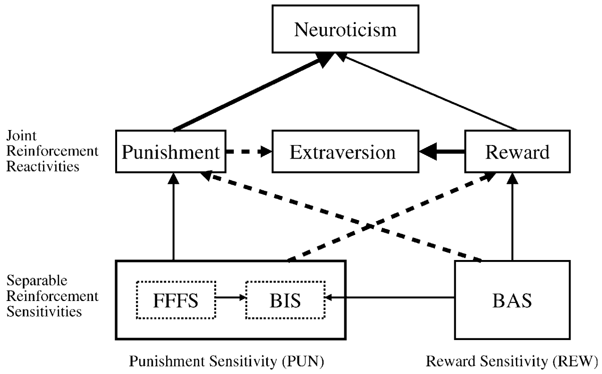

Fig. 2. A schematic representation of the hypothesized relationship between (a) FFFS/BIS (punishment sensitivity; PUN) and BAS (reward sensitivity; REW); (b) their joint effects on reactions to punishment and reward; and (c) their relations to Extraversion (E) and Neuroticism (N). E is shown as the balance of punishment (PUN) and reward (REW) reactivities; N reflects their combined strengths. Inputs from the FFFS/BIS and BAS are excitatory (unbroken line) and inhibitory (broken line)—their respective influences are dependent on experimental factors (see text). The strength of inputs to E and N reflects the 30° rotation of PUN/REW and E/N: relatively strong (thick line) and weak (thin line) relations. The input from Punishment reactivity to E is inhibitory (i.e. it reduces E), the input from Reward reactivity is excitatory (i.e. it increases E). The BIS is activated by simultaneous activation of the FFFS and the BAS, and its activation increases punishment sensitivity. It is hypothesized that the joint effects of PUN and REW gives rise to the surface expression of E and N: PUN and REW represent the underlying biology; E and N represent their joint influences at the level of integrated behaviour.

Anx was associated with a punishment mechanism; Imp with a reward mechanism (we see below how, in the light of recent developments in RST, we might want to clarify these associations). In broad terms, RST predicts that Imp + individuals are most sensitive to signals of reward, relative to Imp − individuals; and Anx + individuals are most sensitive to signals of punishment, relative to Anx − individuals. The orthogonality of the axes was interpreted to suggest: (a) that responses to reward should be the same at all levels of Anx; and (b) responses to punishment should be the same at all levels of Imp (we shall return this matter below). According to Gray's theory, Eysenck's E and N dimensions are derivative factors of the more fundamental punishment and reward sensitivities: E reflects the balance of punishment and reward sensitivities; N reflects their joint strengths. (Fig. 2 depicts an updated version of these relations, which discussed in section 4).

Gray's theory also explained Eysenck's arousal effects: ex hypothesi, on average, punishment is more arousing than reward, and introverts are more sensitive to punishment, therefore introverts experience more induction of arousal and tend to be more highly aroused (physiological support for this hypothesis is available [18])—however, it should be noted that the evidence associating arousal and N is much less consistent. In contrast, Eysenck maintained that, to the extent that reinforcement effects are mediated by personality, they are a consequence of arousal level and not sensitivity to reward and punishment per se [19].

According to Eysenck's arousal theory [7], introverts suffer from anxiety disorders because they more easily develop classically conditioned (emotional) responses; this theory was expanded with the inclusion of incubation effects in conditioning effects [20] to account for the 'neurotic paradox' (i.e. the failure of extinction with continued nonreinforcement of the CS); coupled with emotional instability, reflected in N, this made the introverted neurotic (E − /N +) especially prone to the Anx disorders.

However, from the inception of this arousal-based theory of personality, there were a number of nagging problems. First, introverts show weaker classical conditioning under conditions conductive to high arousal [21]; and a crossover pattern of E × arousal is easily confirmed [22]. Other problems attend Eysenck's arousal-conditioning claims. For example, Imp (inclined into the N plane), not sociability, is often associated with conditioning [21]—this would place high arousability, and thus high conditionability, in the stable-introverted quadrant defined by E × N space, not in the neurotic-introvert quadrant required by the theory. Eysenck originally considered Imp to be a subfactor of E [23], but in later developments of his structural model, it was largely dropped [24]. Thus, Eysenck's theory seems unable to explain the aetiology of anxiety in neurotic-introverts. In addition, time of day effects in E-arousal relations suggested that introverts, let alone, neurotic-introverts, are not chronically over-aroused [25]—as RST's reinforcement processes are not dependent on arousal, these time of day effects are not directly relevant to Gray's theory (although the possibility that reactions to reinforcement show a time of day effect has never been tested).

According to Gray [26], these problems thrust a dagger into the heart of Eysenckian theory. However, for a number of reasons (e.g. temporal effects in conditioning and average levels of arousal/arousability), these factors may not constitute a definitive refutation of Eysenck's theory. More compellingly, Gray [26] provided a superb account of Eysenck's continual (psychometric) refinement of the scales of E and N (as well as Psychoticism, P, which we shall not consider in this paper; see Ref. [27]), which rendered them more consistent with experimental data: however, in so doing, the very logic of discovering dimensions of personality was eroded, as was the force of Eysenck's argument against a rotation of E and N to form dimensions of Anx and Imp: if Eysenck could refine his scales [24,28], and thus affect their rotational position with respect to the original E/N scales [23], then surely Gray should be permitted to do likewise on good empirical grounds (e.g. anxiolytic drugs lower N and raise E, activating a single factor of Anx). Nevertheless, Eysenck [29] continued to argue that the discovery, and subsequent confirmation, by factor analysis of E and N (not Anx and Imp), was a major strength of his description of the dimensions of personality—this stance had considerable force because, unlike other structural models of personality, the original factor analysis was based on a medical checklist of neurotic symptoms [11], not a list of adjectives culled from a good dictionary.

2.3. Conditioning and emotion

Gray identified a more compelling reason for rejecting the classical conditioning theory of neurosis. In consequence of classical (emotional) conditioning, the CS takes on many of the properties of the UCS, and the CR substitutes for the UCR. But the problem is that CR does not substitute for the UCR—in several important respects, the CR does not even resemble the UCR. A pain UCS will elicit a wide variety of reactions (e.g. vocalisation and behavioural excitement) which are quite different to those elicited by a CS conditioned to pain: the latter produces anxiety and a different set of behaviours (e.g. quietness and behavioural inhibition). Thus, classical conditioning cannot explain the pathogenesis of neurosis—although it can explain how initially neutral stimuli (CSs) acquire the motivational power to elicit this state. Now, if the CR is not simply a version of the UCR then what generates the negative emotional state that characterises neurosis? Gray's claim was an innate mechanism, namely the BIS [30,31].

The 1970 formulation of RST gradually developed to include three major systems of emotion. First, the *fight/flight system* (FFS) was hypothesized to be sensitive to *unconditioned* aversive stimuli (i.e. innately painful stimuli), mediating the emotions of rage and panic—this system was related to the state of negative affect (NA) (associated with pain) and Eysenck's trait of Psychoticism. Second, the BAS was hypothesized to be sensitive to *conditioned* appetitive stimuli, forming a positive feedback loop, activated by the presentation of stimuli associated with reward and the termination/omission of signals of punishment—this system was related to the state of positive affect (PA) and the trait of Imp. Third, the BIS was hypothesized to be sensitive to *conditioned* aversive stimuli (i.e. signals of both punishment and the omission/termination of reward) relating to Anx, but also to extreme novelty, high intensity stimuli, and innate fear stimuli (e.g. snakes, blood) which are more related to fear [32]. As we see below, recently this theory has been substantially revised [4], and the distinction between fear and anxiety has been clarified. From only a few empirical papers in the 1970s, RST has now produced a large and growing literature; and Gray has extended RST concepts to the psychiatric classification [33].

3. Human experimental data

This section provides a brief survey of most of the studies conducted to test RST in the human experimental laboratory. As we see, this literature is characterized by: (a) a wide variety of measures of punishment and reward sensitivity (some using E and N; others using purpose-built scales); (b) a wide range of psychophysiological and behavioural tasks; and (c) a bewildering array of experimental findings.

3.1. Classical conditioning

The first systematic studies of personality used eyeblink classical conditioning, employing an innately aversive UCS. Early studies tended to show superior conditioning for high Anx individuals [34], but only in relatively threatening testing environments [35], otherwise superior effects for introversion were found (for a discussion see Ref. [19]). In one of the most thorough investigations, Eysenck and Levey [21] reported complex interactions of stimulus parameters (UCS intensity and CS-UCS interval) and personality (sociability and Imp) on the ease of eyeblink conditioning. These defensive conditioning studies, however, do not allow a strong contrast of Eysenck's and Gray's models as both predict an introvert/anxiety effect (in Eysenck's case, neurotic-introversion, Anx, under emotional conditions).

Opposing predictions are possible with the use of appetitive stimuli: Eysenck's theory must maintain a superiority of introverts (in fact, given TMI, more so than for highly arousing punishment); in contrast, RST predicts a superiority of extraverts. But experimental results have been mixed. Using erotic material as the UCS, Mangan [36] failed to reveal a correlation between E and conditioning; indeed, Barr and McConaghy [37] found that anxious individuals showed the greatest appetitive electrodermal conditioning; and Mangan [38] reported that stable-extraverts (i.e. E+/N−) showed superior GSR conditioning using sexual UCSs. However, more positive findings were reported by Kantorowitz [39]: (a) responses to aversive stimuli were associated with introversion; and (b) responses to appetitive stimuli were associated with E. Paisey and Mangan [40] found that N was negatively correlated with CR acquisition with appetitive stimuli; introversion was related to CR acquisition with weak appetitive stimuli; and extraversion was related to CR acquisition with strong appetitive stimuli—in addition, psychoticism was negatively related to both intensities of appetitive stimuli.

To date, there has not been a thorough study of reinforcement type (appetitive and aversive stimuli), UCS parameters (e.g. strength) and temporal parameters (e.g. incubation effects [20]). Thus, the jury is still out on the question of the significance of classical conditioning studies for testing RST.

3.2. Instrumental conditioning

Verbal operant conditioning studies (based on Taffel's sentence-completion procedure [41] have yielded more positive support for RST. In a series of studies, B.S. Gupta and colleagues in India have reported that extraverts tend to condition best under rewarding conditions, introverts best under punishing conditions [42–46]—it is worth noting that verbal operant conditioning (e.g. 'right' and 'wrong' following a reinforced response) is likely to be more salient in Indian students for cultural reasons: unlike American and European students, students in India (at least those used in Gupta's experiments) are highly deferential to their professors.[2] Perhaps for this reason, failures of this method have been reported in the UK (for a discussion of this discrepancy, see Ref. [27]).

In a sophisticated series of four inter-locking 'go-no go' discrimination experiments, Zinbarg and Revelle [47] reported complex reinforcement × Anx × Imp effects: when individuals learned the task, Imp + individuals, who are also Anx − , rapidly learned to make responses to achieve rewards but had difficulty learning to inhibit responses in order to avoid punishment. In contrast, Anx + individuals, who are also Imp − , rapidly learned to inhibit their responses in order to avoid punishment (Imp + /Anx + and Anx − /Imp − groups also showed poorer learning). Similar joint effects of Anx and Imp have also been reported in relation to classical conditoning [48]. These results do not fit the standard interpretation of RST.

In terms of counter-conditioning, Avila et al. [49] reported that Anx + is associated with poorer learning (i.e. on punished trials that predicted later appetitive reward), a finding that is consistent with the view that low anxious individuals are better able to reduce the aversiveness of punishment by linking it with possible future rewards. Avila [50] reported that individuals with low scores on a purpose-built measure of punishment sensitivity (conceptually similar to Anx) were slower to suppress responses previously rewarded—that is, a failure of extinction—a finding consistent with RST.

3.3. Performance tasks

A wide diversity of specially designed laboratory measures of reinforcement reactivity have been designed to test RST. One of the earliest studies tested peak shift and behavioural contrast in children (for a description of these measures, see Ref. [51]). Nicholson and Gray [52] found superior performance on these measures in E − /N + (trait anxious) children. This finding supported the claim of RST that Anx is related to the state of frustrative nonreward measured by these tasks.

In a study conducted in Eysenck's own laboratory, Seunath [53] found that, on a pursuit rotor task, introverts performed best under punishment (noise), extraverts best under reward (tokens awarded during the task). Similar results have been reported by Boddy et al. [54], using verbal reinforcement on a 'hide-and-seek' computer game and calculations with recoded numbers: in both experiments, introverts performed best under punishment, extraverts best under reward.

Similar observations have also been reported for the allocation of attention (a key output of the BIS). Attentional bias in introverts for punishment-related cues, and in extraverts for reward-related cues, have been reported [55] (see also Ref. [56]). In another study, punishment-sensitive individuals were better at the automatic detection of peripheral, and thus potentially harmful, stimuli; in contrast, reward-sensitive individuals were better able to shift attention consciously when orienting was guided by expectation [57]; however, the relevance of this automatic-controlled distinction in RST has not been fully explored. Consistent with this general line of evidence, Gomez and Gomez [58] showed that purpose-built BIS and BAS scales related to the cognitive processing of unpleasant and pleasant emotional stimuli, respectively.

In a concept learning task with verbal reinforcement (punishment = 'wrong'; reward = 'right'), and monetary reward and punishment (losing from initial gift), Ball and Zuckerman [59] reported complex, and unexpected effects: high Psychoticism and high Reward Expectancy (a measure of the BAS) males learned more quickly when punished, but there were no interactions of reward and personality—however, participants were preselected on the basis of extreme sensation seeking scores, so these are data are difficult to interpret.

Pickering et al. [3] used a computerized maze learning task under control, punishment and reward conditions, with financial incentives as reinforcement. Only one measure of Imp (venturesomeness) was found to be associated with increased maze crossing speed in the reward condition (especially in males); in addition, several measures of Anx were associated with (near-) significant decreases in

[2] I wish to thank Dr Veena Kumari, whose PhD was supervised by Professor B.S. Gupta, for this observation.

crossing speed in the punishment condition, and in the reward condition after maze learning—a set of results that provide only general support for RST.

Increased behavioural inhibition, in a 'go-no go' discrimination task, was reported in high test anxious (TA) individuals by Hagopian and Ollendick [60]; and also of interest was that high TA individuals seemed most reactive in the reward condition (also see Ref. [61]). Once again results were not consistent with RST (for a reanalysis of these data by Pickering and Gray, using signal detection analysis, see Ref. [27]).

Reinforcement × personality studies have also been conducted in the classroom [62,63], a line of research dating back to the 1930s [64,65]. McCord and Wakefield [62] demonstrated that the relative balance of reward and punishment used by teachers was related to classroom attainment in a manner consistent with RST. This is an especially important form of RST research because it holds the promise of considerable practical benefits to educational practice. RST has also been used in other applied settings, for example, in occupational performance [66].

3.4. Passive avoidance and disinhibition

Much attention has been directed to using RST to explain disinhibitory syndromes. One influential model by Gorenstein and Newman [67] proposed that dysfunctional reward reactivity is the common diathesis underlying disinhibited behaviour (e.g. psychopathy, early onset alcoholism, childhood hyperactivity and nonpathological impulsivity), and that this heightened sensitivity has a number of important consequences: it produces a reward-focused dominant response set; it impairs reflection of environmental contingencies; and it leads to a failure to learn from punishment [68]. There have been several reports confirming this prediction [69,70].

Recent RST studies have tended to use purpose-built measures of reward (BAS) and punishment (BIS) sensitivity. In one such study, Avila [71] reported that BAS activation resulted in a lack of inhibition in reward-directed behaviour after introducing an aversive stimuli, as well as deficits in learning from aversive cues when responding to reward. In addition, low BIS individuals extinguished aversive associations more quickly, had a lower generalization gradient (i.e. they extinguish more quickly the aversive properties of stimuli that are similar to the actual aversive stimulus), and showed less interference with appetitive behaviour in the presence of aversive cues. Such results help to clarify why BIS active individuals are, indeed, more anxious.

In an educational setting, Avila and Torrubia [72] reported a meta-analysis of students undertaking important multiple-choice university examinations (in which a fraction of a point is lost for an incorrect answer, i.e. commission error). More errors were made by students scoring low on a punishment sensitivity scale; and omission errors (not attempting a question) were highest in students scoring high on this scale. The precise pattern of effects involving sensitivity to reward and punishment depended on the nature of the examination (e.g. mark level and number of questions). This type of finding supports Gray's claim that in ego-involving, important real-life situations, clear-cut effects of BIS will be more easy to find. In this regard, it is perhaps to be regretted that so few RST studies have looked at such real-life reactions to reinforcement as a function of personality. There is considerable promise in this research strategy, including the use of people who are experiencing extreme life events (e.g. illness [73]).

It should be noted that, compared with Eysenck's scales, these purpose-built scales do not have the same degree of psychometric support or validity evidence; and the degree to which they index basic brain systems is not clear. With changes in the description of RST systems (see below), this issue is even more troublesome. Clearly much more work is required in this area.

Segarra et al. [74] examined passive avoidance under reward only, punishment only and reward plus punishment conditions; and the results showed E − /N + (high Anx) individuals made more passive avoidance errors, but only when the reward plus punishment condition was performed first; and E + /N − (low Anx) individuals tended to display behavioural disinhibition in the punishment only condition, but only when the punishment condition was performed second. As the authors stated:

> These results suggest disinhibition is a complex phenomenon that may be mediated by either BIS hypoactivity, BAS hyperactivity or even BIS hyperactivity, and by the interaction of all these mechanisms with the involvement of some of the variables such as gender, personality, motivation, task and subject's Anx state (p. 239).

We shall return to the putative interdependence of BIS and BAS systems below.

3.5. Psychophysiology

It has proved attractive to test biological models of personality by measuring biological processes directly using peripheral (e.g. skin conductance) and central (EEG and ERPs) nervous system measures—but we should note that direct measures are no more 'biological' than less direct measures such as behavioural or verbal responses. Although there is a large literature on arousal and EEG/ERPs (for a review, see Ref. [75]), relatively few studies have been directed towards RST.

In a number of studies by Bartussek and colleagues, ERP responses in introverts and extraverts have been measured under different reinforcement conditions. In the first study [76], ERPs were elicited by neutral tones and tones signaling gains and losses in a betting task, and in the second study [77] ERPs were elicited by the presentation of emotionally positive, negative and neutral adjectives. Taken together, results from both studies failed to support RST, as introverts had greater ERP amplitude in the neutral condition (itself not inconsistent with RST) and extraverts had greater ERP amplitudes to both reward and punishment (inconsistent with RST, but consistent with arousal theory). More consistent with the predictions of RST, in a third study [78], ERPs were measured in response to stimuli signaling winning or losing in a gambling task: extraverts had higher P200 amplitude in the win condition. However, a failure to replicate these results has been reported [79]; although, more consistent with RST, a significant positive relationship between the individual sensitivity of the BAS and a P600 peak amplitude to stimuli of reward was observed.

DePascalis et al. [80] recorded ERPs to emotionally positive and negative adjectives during four emotional-word recognition tasks, using a visual oddball paradigm. Consistent with RST, frontal and temporal P300 amplitude was larger in Anx + individuals for unpleasant words; but Imp + showed smaller P300 peaks for negative targets over parietal and occipital cortical areas, and longer P300 latencies across frontal, temporal, parietal and occipital sites. The expected amplification of the response to positive emotion in the Imp + group was not confirmed. Asymmetries in the processing of pleasant and unpleasant stimuli have also been investigated [81], and these might be an important target for future ERP studies of RST [82].

In a study that used psychophysiological measures, as well as self-rating and reaction time (RT), DePascalis and Speranza [83] reported that extraverted-sensation seekers (putative high BAS activity) had higher ratings for pleasant words; and Anx + individuals had larger heart rate accelerations for unpleasant words; however, Anx + individuals also had slower RTs in detecting both pleasant and neutral cues.

Too few RST-relevant ERP studies have been conducted. In future research, it will be necessary to specify which ERP components, from which electrode sites, relate to reactions to specific types of reinforcing stimuli. This research should be greatly facilitated by rapid advances in cognitive neuroscience.

3.6. Induced emotion

Several studies have examined the relationship between E/N and positive affect (PA) and negative affect (NA). Consistent with previous associations of these sets of variables [84], Eysenck proposed that E was associated with PA, N with NA [19]. These associations were forced by brute empirical reality, not by theory: there is nothing in arousal theory to suggest a link between E and PA, save the general proposition that an optimal level of arousal—not itself necessarily typical of extraverts—is related, in some undefined way, to optimal hedonic tone (i.e. PA).

Consistent with RST, Larsen and Katelaar [85] reported that NA was highest in E − /N + (high Anx) individuals; but inconsistent with theory was the finding that PA was highest in E + /N − (low Anx) individuals, not E + /N + (high Imp) individuals. These results do not fit Eysenck's model, and nor does the association of induced PA and low Anx fit comfortably into the standard view of RST (but see below). In a similar study, Gomez et al. [86] found that NA was positively correlated with N, as well as N × E interaction; and PA was positively correlated with E. Rusting and Larsen [87] found that NA was highest in E − /N + individuals, and PA in E + individuals. These results are generally consistent with RST [17], although they do not conform to all the specifics of the theory.

In the development of what have become influential scales, the Carver and White [88] BIS–BAS scales provide one measure of the BIS, and three subscales of the BAS (reward responsiveness, fun seeking, and drive). Carver and White reported that the BIS scale was the best predictor of self-reported levels of nervousness induced by a cold-pressor test (i.e. placing hand into ice water) and failure feedback on a computer task; BAS reactivity was the best predictor of reactions to success feedback, indicating the gaining of reward credits for experimental participation (the BAS subscales of Drive and Reward Responsiveness best predicted self-reported happiness).

Examination of the relations between BIS/BAS sensitivities and the effects of daily events on positive and NA have yielded intriguing results. Gable et al. [89] found that positive events were associated with changes in PA, whereas negative events were associated with changes in NA; however, there are also some unexpected findings: negative events covaried with daily PA (reducing it); and the BIS scale predicted average daily PA (suppressing it). The type of pattern reported here for every-day affect parallels some of the human experimental data already presented above (the fit of these data with RST is discussed in detail below).

In medical settings, the sensitivity to punishment scale (another purpose-built measure of BAS functioning [90]) has been found to be the best predictor of medical fears, blood phobias and social phobia [91], indicating that such measures of punishment sensitivity are related to actual every-day fears. In an innovative experimental game setting, Brandstatter and Guth [92] studied saving and consumption consumer decisions (defined as an economics-based *intertemporal utility function*) as a function of life expectancy. It was found that E − /N + (high Anx) individuals responded most, and E + /N − (low Anx) individuals least, to this expected form of punishment.

In studies using purpose-built BIS–BAS measures, it would be valuable to compare them with E and N measures; by this means it should be possible to determine which set of measures, if any, provide 'clean' predictors of reward and punishment reactivities.

In conclusion of this section, there is a diversity and complexity of findings in RST research, which at times are highly confusing and suggestive of a failure of RST to provide a coherent account of the causal dynamics of personality. There is also some confusion concerning the nature of reinforcement (e.g. the distinction between emotional and motivational components) that may play an important role in determining personality effects. Indeed, the state of this literature has prompted some leading personality researchers to question the utility of pursuing a strictly biological approach [15]. Before we can tackle this problem, and attempt to provide a solution, we need first to summarise a major revision to RST [4].

4. Gray and McNaughton (2000) revised theory

Theory clarification and development are desirable and signs of a progressive science—theory modification is less welcome when it is primarily designed to shore up theoretical cracks revealed by empirical data. The recent revision of the original BIS theory represents a major revision and clarification of RST, based upon principled arguments (indeed, in some ways, it undermines some of the central postulates of the earlier theory, e.g. the categorical distinction between unconditioned and conditioned aversive stimuli; see Ref. [2]). The new theory has a more elaborate neurophysiology, and it makes new predictions especially with regard to the elicitation of fear and Anx in the context: (a) of an ethoexperimental framework; and (b) of goal conflict.

The revised theory postulates three systems.

1. The *fight–flight–freeze system* (FFFS) is responsible for mediating reactions to all aversive stimuli, conditioned and unconditioned (unlike the old FFS, which was activated by unconditioned stimuli only). A hierarchical array of modules comprises the FFFS, responsible for avoidance and escape behaviours. Importantly, the FFFS does not mediate Anx—it is associated with the emotion of fear.
2. The *BAS* remains largely unaltered in the revised theory. As before, it mediates reactions to appetitive stimuli; but now this includes all appetitive stimuli (including unconditioned ones).
3. The *BIS* now does not mediate reaction to aversive stimuli per se—this is the responsibility of the FFFS—but is now responsible for resolving *goal conflict* in general (e.g., between BAS (approach) and FFFS (avoidance)). This process generates the state of Anx. As in the former version, the BIS inhibits prepotent conflicting behaviours, and it initiates risk assessment scanning of memory to resolve goal conflict. Subjectively this state is experienced as worry and rumination, and a sense of possible danger/loss.

Changes in the values of reward and punishment (conflict) inputs to the BIS will affect the degree of BIS activation; that is, both reward and punishment sensitivities will determine whether a conflict is detected and to what extent. However, according to the revised theory, the sensitivity of the BIS mechanism itself is independent of these reinforcement sensitivities.

This revision of RST raises new problems for personality. For example, it raises the question of which traits now correspond to the FFFS, BAS and BIS (the implications of the new theory for personality is discussed elsewhere; see Ref. [93]). A major task of future RST research will be to clarify these systems–personality relations.

For the moment we relate (a) punishment sensitivity to combined FFFS/BIS functioning; and (b) reward sensitivity to BAS functioning. For convenience, we relate punishment sensitivity to neurotic-introversion, and reward sensitivity to neurotic-extraversion (see Fig. 1). It may prove necessary to dissociate FFFS and the BIS at the level of personality to reflect the dissociation found at neurophysiological, neurochemical and behavioural levels; however, it is also possible that a general factor of N relates to both systems [2]. It is encouraging that the Blanchards have already began work on relating typical animal defensive behaviours to typical defensive behaviours observed in human beings [94]—the Blanchards' ethoexperimental and pharmacological work has played an important part in the revised Gray and McNaughton theory [4]. The obvious next step would be to relate these specific human defensive behaviours to well-established personality traits.

Much, but not all, of the empirical literature reviewed above is applicable to the reviewed theory; however, test of the new theory will require new data, collected using designs appropriate to its specific postulates. There is, however, one interpretation of these data that finds comfort within the revised theory: the idea that reinforcement systems are mutually interdependent in their functional outputs.

5. Personality in the human experimental laboratory

Although it is yet to be seen whether the revised theory is better able to generate consistent and interpretable data, one strength is its more detailed account of the cognitive processes of fear and anxiety—the apparent neglect of the cognitive nature of fear/anxiety has been a common criticism of the old model. For example, in a comparative review of Eysenck's and Gray's biological theories of personality, Matthews and Gilliland [15] concluded:

> Cognitive constructs may be more appropriate than biological ones for explaining the majority of behaviours, so that explanations of the kind offered…are relevant to a restricted range of phenomena only (p. 620).

In a reply to this conclusion, Corr [73] discussed a number of hidden complexities in RST that, at present, hinder the derivation of precise experimental hypotheses necessary for the test of the theory's specific claims in human beings. It was argued that the range of phenomena to which RST is applicable is much broader than sometimes assumed (also see Ref. [95]). These points are just as relevant to the revised theory as they were to the original theory.

The view that RST may be limited in terms of its implications for personality psychology, especially as one capable of replacing Eysenck's theory expressed by others [96]. Matthews and Gilliland [15] critique highlighted the difficulty of translating concepts from animal to human studies, and the problems inherent in operationalising RST constructs—these issues have not received the consideration they clearly deserve. In this respect, in Section 5.1, one major problem is addressed: the putative interdependence of the reward and punishment systems. Consideration of this problem may help to resolve the apparent contradiction in the existing literature; and it may point to new hypotheses to test personality and reinforcement relations.

5.1. Separable or joint subsystems?

In a recent clarification of RST, Corr [73] proposed a revision to take into account the mutual interplay of punishment sensitivity and reward sensitivity—that is, BIS and BAS effects in terms of the old theory, but in terms of the revised Gray and McNaughton theory [4], FFFS/BIS[3] and BAS, respectively (for clarity, in this section, REW will be used to denote reward sensitivity, and PUN, punishment sensitivity).

Fig. 1 shows the locations of REW and PUN relative to E and N. Labeling the PUN axis as 'anxiety' is called into question in the revised theory, which makes a clear distinction between fear (FFFS) and anxiety (BIS)—if anything, FFFS (fear), not BIS (anxiety), is more associated with general punishment sensitivity (PUN). However, with respect to the factor positions of E and N, at present we cannot be sure that PUN relates to fear alone or fear plus anxiety. However, the revised theory is clear that fear and anxiety are separate, albeit overlapping, processes, and it is likely that separate personality factors correspond to these different processes (whether these factors relate in any straightforward way to E and N is an unresolved issue). Fig. 1 is presented to highlight this problem, not resolve it.

Virtually all studies of RST have adopted the *separable subsystems hypothesis* (SSH) of PUN and REW. This hypothesis predicts that, on average, Rew + (ex hypothesi, strong BAS) individuals should be most reactive to reward, relative to REW − (ex hypothesi, weak BAS) individuals; and PUN + (ex hypothesi, strong FFFS/BIS) individuals should be most reactive to punishment, relative to PUN − (ex hypothesi, weak FFFS/BIS) individuals. The proposed orthogonality of REW and PUN suggests: (a) that responses to reward should be the same at all levels of PUN; and (b) responses to punishment should be the same at all levels of REW. An important caveat here is that 'reward' is defined as stimuli that activate the BAS; and 'punishment' as stimuli that activate the FFFS/BIS; of course, in order to avoid circularity, it is necessary to provide definitions of reward and punishment that are independent of their power to activate the BAS and the FFFS/BIS, respectively (see Ref. [73]).

5.2. Joint subsystems hypothesis: background

In contrast to the SSH, the *joint subsystems hypothesis* (JSH) [73] postulates that, under certain experimental conditions, REW and PUN exert interdependent, or joint effects. Specifically, it is proposed that there are two effects of each reinforcement sensitivity: (a) facilitatory, and (b) antagonistic. REW facilitates responses to appetitive stimuli, and antagonises responses to aversive stimuli; PUN facilitates responses to aversive stimuli, and antagonises responses to appetitive stimuli. The JSH has been conceptualised in terms of the FFFS/BIS activation by aversive stimuli inhibiting the BAS and BAS activation by appetitive stimuli inhibiting the FFFS/BIS [73]. The precise ways in which these systems interact is discussed in detail by Corr and McNaughton [93].

The JSH does not state that PUN and REW interdependences will always be found. Separable effects should be found under the following experimental conditions: (a) when strong appetitive/aversive stimuli are used; (b) when PUN + and REW + individuals are tested; (c) in experimental situations that do not contain mixed appetitive and aversive stimuli; and (d) where there is not a need for rapid attentional and behavioural shifts between aversive and appetitive stimuli. These conditions do not typically prevail in the human experimental laboratory; and it is under these less than ideal conditions that effects consistent with the JHS are predicted. Experimental effects consistent with the JSH are predicted to be found with weak appetitive/ aversive stimuli, in non-extreme PUN and REW individuals, in environments containing mixed appetitive/aversive stimuli, and where rapid attentional and behavioural shifts between reinforcing stimuli are required [73].

Confirmation of the JSH does not rely upon a statistical interaction of PUN and REW; for example, under nominally rewarding conditions, there may be a main effect of PUN (with low PUN scores relating to stronger reactions to reward [97] an example of an antagonistic effect).

[3] Activation of the FFFS will activate the BIS only when there is goal conflict, and activation of the BIS is expected to enhance state activity in the FFFS. Although there may be separate traits corresponding to the FFFS and BIS [93], for present purposes I assume punishment sensitivity (PUN) is a reflection of the general activity of both systems.

The precise pattern of joint effects will determine the precise pattern of statistical findings.

Fig. 2 shows the relationship between punishment (FFFS/BIS) sensitivity and reward (BAS) sensitivity. It illustrates how joint effects of reinforcement sensitivities influence reinforcement reactivities. Assuming non-dominance of one system, it is expected that E reflects the balance of these reactivities (with a greater excitatory link from REW than the inhibitory link from PUN), and N their combined strength (with a stronger excitatory link from Pun than from REW). This pattern of inputs is consistent with the 30° rotation of E and N suggested by Gray [16]. Seen in the light of the JSH, there is one important conclusion from this set of PUN and REW influences in E and N: E and N capture the joints effects of PUN and REW and thus represent, at the surface level of personality description, viable factors in an appropriate rotational position. This conclusion may explain why E and N are frequently found in exploratory studies of personality (the role of factor analysis and the location of factors in the context of RST is discussed by Corr and McNaughton [93]). Accordingly, at the general level of description, where joint effects are expressed, it may be inappropriate to rotate E and N to PUN and REW factors that assume separable effects on behaviour.

The possibility of joint effects was articulated in a review of RST data from Gray's own laboratory. Pickering et al. [14] stated:

> While it is possible that one system (the system more strongly engaged by the prevailing eliciting stimuli) could gain control of behaviour, it seems more plausible to suggest that the net behavioural effect of the activity of the two systems will reflect a more complex mixture of their joint action (p. 40).

These joint effects could result from an environment containing both aversive and appetitive stimuli, or from an impurity in nominally 'aversive' or 'appetitive' stimuli (e.g. using money to manipulate reward, which in some individuals may be perceived as frustrative nonreward and hence aversive; see Ref. [98]). Indeed, the position stated in the JSH is not new, and has been suggested by the work of other RST researchers (see Ref. [67]). For example, Pickering et al. [3] have expressed the possibility of joint effects in relation to the maze learning experiment (see above):

> The coexistence of anxiety and impulsivity correlations, particularly in reward, confirmed predictions that nominal 'punishment' and 'reward' conditions may activate both systems simultaneously (p. 541).

However, the first formal expression of PUN and REW interdependency was made by Gray et al. [99] in a discussion of the role that low anxiety plays in affective modulation of startle reflex by appetitive stimuli [97] (see below). Joint effects were also reported by Corr et al. [100], in relation to reinforcement and personality effects in instrumental learning: approach learning, under rewarding conditions, was superior in Anx − individuals; and passive avoidance behaviour, under punishing conditions, was superior in Imp − individuals. These results implied that high Anx impairs reactions to appetitive stimuli, and high Imp impairs reactions to aversive stimuli—that is, they are exerting antagonistic effects. These 'complementary trait effects' have been discussed by Pickering et al. [14] in relation to data from Gray's own laboratory:

> Although the functional capacity of the BIS and BAS might, as assumed, be largely independent, the functioning of the two systems (in terms of their net behavioural effects) may not. In this way, a subject with a high score on a personality trait reflecting BIS reactivity may respond to stimuli that activate the BIS to an extent which also reflects their (independent) individual level of BAS reactivity (p. 40).

Anyone familiar with the reciprocal inhibitory links between punishment and reward mechanisms in the early Gray and Smith arousal-decision model [101], which has played an important role in RST, would not be surprised to learn of these interdependencies; but what is surprising is that these possible reciprocal inhibitory effects have not significantly influenced thinking and research in RST in the human experimental (laboratory). For example, in their insightful analysis of Hagopian and Ollendick's data [60], Pickering and Gray [27] noted:

> This still leaves the puzzle…of why low Anx subjects should show a sizable increase in response bias under predominantly reward conditions (p. 126/127).

Also, in relation to verbal operant conditioning results [45], Pickering and Gray [27] stated:

> Thus, impulsivity and sociability (extraversion) measures did appear to mediate operant conditioning under positive verbal reinforcement, but impulsivity also mediated conditioning under punishing verbal reinforcement. The latter effect is not predicted by RST (p. 125).

These quotes are clear statements of the standard (SSH) view of RST. In contrast, the JSH is consistent with Hagopian and Ollendick's finding that low Anx is associated with reactivity to reward (ex hypothesis, PUN + antagonises reactions to reward under weak appetitive conditions), as well as the finding that high Imp is sometimes associated with (weak) reactivity to punishment (ex hypothesis, REW + antagonises reactions to punishment under relatively weak aversive conditions).

One strength of the SSH is simplicity and clarity; the chief merit of the JSH is its consistency with (at least some) experimental data—in this respect, it is important that it is used to predict experimental findings based on a careful consideration of operational factors [98], rather than as a device post hoc to account for anomalous findings—that is, it is not used as a Kuhn-like auxiliary hypothesis to buffer RST from the chill winds of empirical challenge. It is presented as a heuristic hypothesis, representing a 'staging-post', to reflect upon progress to date, on the journey towards the final destination of a viable neuropsychological theory of personality (the next leg of the journey is already in an advanced stage of planning [93]—for a preview of further developments, see Ref. [2]).

5.3. Experimental evidence: postdiction

A summary of evidence from Gray's own laboratory demonstrates the complexity of effects often reported [14]. Some studies have confirmed the association of PUN and reactions to aversive stimuli. For example, Corr et al. [102] demonstrated that Anx + individuals showed superior procedural learning under punishment, and inferior learning under a neutral condition; and Corr et al. [97,103] showed that electromyographic (EMG) startle reactions to unpleasant slides were greatest in Anx + individuals. However, other studies have yielded inconsistent results [104].

In the case of reward-mediated responses, the situation is even more complex. For example, PUN − is sometimes found to be associated with appetitive responses, whether assessed by EMG startle reactions to pleasant slides [97], induced positive emotion [85], instrumental approach behaviour [100], or appetitive classical conditioning [36,40]. In addition, hedonic tone is consistently related to E + /N − (Anx −), not E + /N + (Imp +) [15]. Sometimes Imp is not related to reward, either in terms of the learning of reward expectancies or behavioural responses to rewarding stimuli [104].

In addition, complex Anx × Imp interactions are sometimes reported [47]. In an understatement of the complexity of this literature, Zinbarg and Mohlman [104] concluded:

> …the interactive effect of impulsivity by trait anxiety…is not well understood at present (p. 1038).

In their study of the relations between BIS/BAS measures and daily events in PA and NA, Gable et al. [89] noted:

> There were also some unexpected findings: Negative events covaried with daily PA, and BIS predicted average daily PA (p. 1148).

That is, people reported higher PA on days they had more positive events and fewer negative events. Of course, such a result would not be 'unexpected' to the proverbial 'man in the street'!

The above anomalous effects, in large measure, are consistent with the JSH, but it is always less than satisfactory to base support for a new theory on post hoc (re)interpretation. Recently, a number of studies have been devoted to contrasting the predictions of the SSH and the JSH, including one that applied these hypotheses to explain the personality basis of the belief in the ultimate form of reinforcement, namely religiosity [105]!

5.4. Experimental evidence: prediction

Corr [106] reported two studies that lent support to the JSH. The first study used the affective modulation of the startle reflex paradigm. The results revealed that the strongest reaction to unpleasant slides, compared with neutral slides ('fear potentiated' startle) was found in Anx + and Imp − individuals (in the Anx + /Imp + group, fear-potentiated startle was not statistically significant). This pattern of effects is consistent with the view that PUN facilitates reactions to aversive stimuli and REW antagonises these reactions. However, in this study, there were no effects for reactions to appetitive stimuli, either relating to the separable or joint subsystems (see Ref. [106] for possible reasons). In the second study, the number of false alarms (commission errors) on a rapid visual information processing task were highest under (monetary) punishment of commission errors (compared with feedback-alone) in Anx − /Imp + individuals: it was as if the PUN + mediated brake cable on punishable responses was cut, leaving REW + Imp to run free (however, these effects were observed only under high, caffeine-induced, arousal).

The JSH has also received support from other laboratories. Using a 'stop-signal' task, which is a measure of post-response inhibitory processing, inhibitory deficits were associated with both PUN − and REW + [107].

In a study examining the relationship between personality scales of reward and punishment sensitivity and substance abuse in 4501 Russian youths, Knyazev [108] concluded:

> The interaction of BAS and BIS found in the present study generally confirms Corr's (2002) hypothesis. The association of BAS with RWP (*Relationships with Parents*) was more pronounced in individuals with low BIS (submitted).

In a separate study of 768 Russian adolescents by Knyazev and Wilson [109], a similar PUN and REW interaction was observed in prediction of adolescent's adjustment problems: consistent with the JSH, PUN moderated the relationship between REW and self-reported conduct problems and emotional symptoms (i.e. REW + significantly predicted conduct problems, but only in PUN − individuals). In addition, PUN + predicted emotional symptoms, but only in REW + individuals—as argued elsewhere [97], REW + can lead to frustration and anger in the form of frustrative nonreward, thus giving rise to PUN + and REW + in dysfunctional emotions (for a discussion of the relationship between the BAS and anger, that helps to explain these associations, see Ref. [110]).

In a comparison of the separable and joint subsystems hypotheses, using affective modulation of mismatch negativity (MMN) obtained through auditory event-related potentials, DePascalis et al. [111] concluded:

> In line with the JSH results show that: (1) SP + subjects displayed a higher MMN peak over frontal and central scalp sites in presence of unpleasant slides as compared to positive or neutral one, but this effect was stronger in SP + /SR − participants, indicating that sensitivity to reward antagonizes this BIS-mediated response; and (2) SR + participants displayed an enhanced MMN peak in absence of pleasant (compared to neutral) slides, but this effect was more pronounced in SR + /SP − subjects (submitted).

Although the PUN/REW pattern for negative slides was,

> …remarkably close to the theoretical predictions of the joint susbsytems hypothesis…for the positive slide condition our experimental outcomes did not match the theoretical predictions. Although the magnitude pattern vaguely resembled the theoretical prediction, it failed to reach any significant level of difference between groups…although our results are not in direct contrast with Gray's theory, some of our results are misfitting and better accounted for by Corr's (2001, 2002) joint subsystems hypothesis.

In the ERP study, already discussed above, DePascalis et al. [80] stated:

> Findings obtained for both P3 peak amplitudes and latencies do not appear to support the positive relationship between Imp and positive emotion, as predicted by the original RST theory. These findings, on the other hand, appear in line with the "joint subsystems hypothesis" (Corr, 2002) that predicts for the impulsive subjects at all levels of anxiety a lower level of sensitivity to signals of punishment (p.888 Corr, 2002).

Other studies contrasting these theoretical positions have provided support for both hypotheses, indicating that they are complementary rather than opposing account of reinforcement-personality processes, as proposed by Corr [73]. Gomez et al. [112] tested participants on three tasks measuring pleasant, unpleasant and neutral information (processing of words; free-recall of words; and developing stories of emotionally ambiguous statements). Although the findings were mixed, the authors concluded that the results for the word processing and free recall tasks were consistent with the SSH, the results for the more ambiguous story completion task was consistent with the JSH.

In their meta-analysis of university multiple-choice university examinations, using Sensitivity to Punishment (SP) and Sensitivity to Reward (SP) scales and analysing commission and omission errors, Avila and Torrubia [72] reported:

> Our main hypothesis was that non-anxious, impulsive and extraverted personalities would have a higher probability of making errors by responding than omitting, whereas their counterparts would have the opposite tendency. Based on mean effect sizes, analyses showed that SP was more strongly related to these differences in performance than SR. However, the strongest effect size was found for the comparison between SP − SR + and SP + SR − groups (p.52).

In this study, it was interesting that expectations of success and failure moderated the pattern of personality on performance in multiple-choice examinations. The importance of this factor in RST studies has been discussed elsewhere [73].

Less positive support was reported by Kambouropoulos and Staiger [113], who used a measure of behavioural inhibition (the 'Q-task' [114]). They found that PUN + and REW + individuals showed the greatest inhibition. Although the putatively BIS-mediated Q-task response involved both PUN and REW scales, the pattern of effects were not consistent with the JSH (which predicts a PUN + / REW − pattern); however, nor are these results consistent with the SSH. In such studies, other factors, not explained by either hypothesis, seem to be operating.

Lately, there has been an increasing recognition for the interplay of systems. For example, Van Yperen [115] noted that, despite the assumed independence of the constructs of NA and PA, there is a negative link between NA and job performance, but only in low PA individuals (i.e. PA + buffers the negative effect of NA + on job performance). Once again, we see the antagonising effects of alternate reinforcement systems on integrated behaviour.

5.5. Neural network simulations

Pickering [6] used neural network simulation methods in an attempt to explore the implications of the JSH (although the hypothesis had yet to acquire this particular name). This work showed that a simple model in which BIS and BAS mutually antagonised one another produced a range of experimental outcomes, depending on the assumption about the relative strengths of the inputs to the BIS and the BAS. The conclusions of this model may still apply even though now we might prefer to relabel the BIS components of the model 'FFFS/BIS'.

Specifically, Pickering considered a case in which RST was true and evaluated the kinds of results which might turn up in standard RST experiments (with various reasonable patterns of BIS and BAS inputs). These simulations revealed a number of relationships between BAS personality traits and responsiveness to reward, and BIS personality traits and responsiveness to punishment, comprising positive, negative, and curvilinear effects. In addition, Pickering described one other pattern of results which has been found in RST studies: the so-called 'complementary trait effect', in which the trait hypothetically associated with the FFFS/BIS or BAS would be associated with responsiveness to inputs hypothetically activating the complementary system. For example, a person with a low level of FFFS/BIS-related personality trait would respond significantly more strongly to a reward than a person with a high level of FFFS/BIS-related trait. As we have already seen, these effects have been observed in a number of RST experiments.

Furthermore, Pickering found that, by making further reasonable assumptions concerning arousal, it was possible to generate a complementary trait effect in these simulations. However, in all those simulations which produced a complementary trait effect, an 'appropriate trait effect' of at least similar strength was always observed. This outcome conflicts with almost all the real experiments that have reported a complementary trait effect either in isolation or combined with an inverse effects for the appropriate trait.

Thus, we may conclude that there is some support for the JSH, but the precise pattern of effects seem highly dependent: (a) on the type of task employed; (b) the specific scales used to measure PUN and REW traits (of which there are many); (c) the operational definition of reward and punishment; and (c) the expectancies of reward and punishment either preexisting or induced during early stages of the experimental procedure (for a discussion of these issues, see Refs. [73,98,106]). Further experimental work will be needed to test the operating conditions and validity of the JSH. In this respect, it would be valuable to take the lead from Pickering [6] and pursue formal computational modelling of RST processes: at the very least, this formal-quantitative approach would serve to sharpen our verbal-qualitative reasoning. Linked to this modelling should be biochemical and pharmacological evidence relating to systems interdependence (e.g. 5HT modulation of dopamine pathways).

6. Conclusion

In the intervening 30 years since the 1970 publication of RST, numerous studies have been conducted and there is now a consensus concerning the fundamental importance of reinforcement processes in personality, including the effects of personality on everyday behaviour [116,117]; as noted by Pickering et al. [14]:

> …one cannot but remain impressed by the sheer frequency with which significant relationships nonetheless do emerge between one or other relevant personality trait and one or other relevant change in behaviour due to reinforcement effects. Somewhere in the human brain there clearly are systems which influence individual differences in sensitivity to reinforcement (p. 63).

During these intervening years, the details of RST have been elaborated and revised, and we now appreciate the full complexity of individual differences in reinforcement processes in human personality. To the extent that awareness of the extent of the problem is a sign of scientific understanding then RST has significantly advanced our knowledge of the true nature of the biological basis of personality. However, the diversity of findings reported indicates that we still only part way to understanding personality dynamics. The aim of this paper is to take stock and reflect on progress to date before embarking on the next stage of the journey.

The rapidly developing neuroscience of personality owes much to Jeffrey Gray's major contribution to an area of psychology that was left for far too long to wither in the infertile fields of data-retardant theoretical speculation and statistical indecision. Now that the potential of genomic analysis is already a reality [118], neuroimaging techniques are being directed at functional analysis of emotion processing and personality [119,120], including the test of RST predictions [121], and sophisticated ethoexperimental [94], behavioural [27] and psychometric [122] approaches are being developed, RST should prove invaluable in providing the conceptual and neural foundations to guide personality research for the foreseeable future.

Acknowledgements

I am indebted to Dr Alan Pickering for his perceptive comments on an earlier draft of this paper. The paper also benefited from the comments of two anonymous reviewers.

References

[1] Depue RA, Collins PF. Neurobiology of the structure of personality: dopamine, facilitation of incentive motivation, and extraversion. Behav Brain Sci 1999;22:491–533.
[2] NcNaughton N, Corr PJ. A two-dimensional neuropsychology of defense: Fear/anxiety and defensive distance. Neurosci Biobehav Rev 2004; 28, this issue, doi:10.1016/j.neurobiorev.2004.03.05.
[3] Pickering AD, Diaz A, Gray JA. Personality and reinforcement: an exploration using a maze-learning task. Personal Individual Differences 1995;18:541–58.
[4] Gray JA, McNaughton N. The Neuropsychology of anxiety: an enquiry into the functions of the septo-hippocampal system. Oxford: Oxford University Press; 2000.
[5] Gray JA. Pavlov's typology. Oxford: Pergamon Press; 1964.
[6] Pickering AD. The conceptual nervous system and personality: from Pavlov to neural networks. Eur Psychol 1997;2:139–63.

[7] Eysenck HJ. The biological basis of personality. Springfield, IL: Thomas; 1967.
[8] Hebb DO. The organization of behaviour: a neuropsychological theory. London: Wiley; 1949.
[9] Hebb DO. Drives and the C.N.S. (Conceptual Nervous System). Psychol Rev 1955;62:243–54.
[10] Gray JA. Learning theory, the conceptual nervous system and personality. In: Nebylitsyn VD, Gray JA, editors. The biological bases of individual behaviour. New York: Academic Press; 1972. p. 372–99.
[11] Eysenck HJ. Types of personality: a factorial study of 700 neurotics. J Ment Sci 1944;90:859–61.
[12] Eysenck HJ. Personality and experimental psychology: the unification of psychology and the possibility of a paradigm. J Personal Social Psychol 1997;73:1224–37.
[13] Corr PJ. Reflection on the scientific life of Hans Eysenck. Hist Philos Psychol 2000;2:18–35.
[14] Pickering AD, Corr PJ, Powell JH, Kumari V, Thornton JC, Gray JA. Individual differences in reactions to reinforcing stimuli are neither black nor white: to what extent are they Gray? In: Nyborg H, editor. The scientific study of human nature: tribute to Hans J. Eysenck at eighty. London: Elsevier; 1997. p. 36–67.
[15] Matthews G, Gilliland K. The personality theories of H.J. Eysenck and J.A Gray: a comparative review. Personal Individual Differences 1999;26:583–626.
[16] Gray JA. The psychophysiological basis of introversion–extraversion. Behav Res Ther 1970;8:249–66.
[17] Pickering AD, Corr PJ, Gray JA. Interactions and reinforcement sensitivity theory: a theoretical analysis of Rusting and Larsen (1997). Personal Individual Differences 1999;26:357–65.
[18] Knyazev GG, Slobodskaya HR, Wilson GD. Psychophysiological correlates of behavioural inhibition and activation. Personal Individual Differences 2002;33:647–60.
[19] Eysenck HJ, Eysenck MW. Personal and individual differences: a natural science approach. New York: Plenum Press; 1985.
[20] Eysenck HJ. The conditioning model of neurosis. Behav Brain Sci 1979;2:155–99.
[21] Eysenck HJ, Levey A. Conditioning, introversion–extraversion and the strength of the nervous system. In: Nebylitsyn VD, Gray JA, editors. Biologcal bases of individual behaviour. London: Academic Press; 1972. p. 206–20.
[22] Corr PJ, Pickering AD, Gray JA. Sociability/impulsivity and caffeine-induced arousal effects: critical flicker/fusion frequency and procedural learning. Personal Individual Differences 1995;18: 713–30.
[23] Eysenck HJ, Eysenck SBG. Eysenck personality inventory. London: University of London Press; 1964.
[24] Eysenck HJ, Eysenck SBG. Manual of the Eysenck personality questionnaire (adults). London: Hodder and Stoughton; 1975.
[25] Humphreys MS, Revelle W. Personality, motivation and performance: a theory of the relationship between individual differences and information processing. Psychol Rev 1984;91:153–84.
[26] Gray JA. A critique of Eysenck's theory of personality. In: Eysenck HJ, editor. A model for personality. Berlin: Springer; 1981. p. 246–76.
[27] Pickering AD, Gray JA. Dopamine, appetitive reinforcement, and the neuropsychology of human learning: an individual differences approach. In: Eliasz A, Angleitner A, editors. Advances in individual differences research. Lengerich, Germany: PABST Science Publishers; 2001. p. 113–49.
[28] Eysenck HJ, Eysenck SBG. Manual of the Eysenck personality scales. London: Hodder and Stoughton; 1991.
[29] Eysenck HJ. General features of the model. In: Eysenck HJ, editor. A model for personality. Berlin: Springer; 1981. p. 1–37.
[30] Gray JA. The behavioural inhibition system: a possible substrate for anxiety. In: Feldman MP, Broadhurst AM, editors. Theoretical and experimental bases of behaviour modification. London: Wiley; 1976. p. 3–41.
[31] Gray JA. The neuropsychology of anxiety: an enquiry into the functions of the septo-hippocampal system. Oxford: Oxford University Press; 1982.
[32] Gray JA. The psychology of fear and stress. Cambridge: Cambridge University Press; 1987.
[33] Gray JA. Framework for a taxonomy of psychiatric disorder. In: van Goozen SHM, van de Poll NE, Sergeant JA, editors. Emotions: essays on emotion theory. Hove: Lawrence Erlbaum; 1994. p. 29–59.
[34] Spence KW. Anxiety (drive) level and performance in eyelid conditioning. Psychol Bull 1964;61:129–39.
[35] Ominsky M, Kimble GA. Anxiety and eyelid conditioning. J Exp Psychol 1966;71:471–2.
[36] Mangan GL. Personality and conditioning: some personality, cognitive and psychophysiological parameters of classical appetitive (sexual) GSR conditioning. Pavlovian J Biol Sci 1974;13:226–35.
[37] Barr RF, McConaghy N. Anxiety in relation to conditioning. Behav Ther 1974;5:193–202.
[38] Mangan GL. Factors of conditionability and their relationship to personality types. Pavlovian J Biol Sci 1978;13:226–35.
[39] Kantorowitz DA. Personality and conditioning of tumescence and detumescence. Behav Res Ther 1978;16:117–23.
[40] Paisey TJH, Mangan GL. Personality and conditioning with appetitive and aversive stimuli. Personal Individual Differences 1988;9:69–78.
[41] Taffel C. Anxiety and the conditioning of verbal behaviour. J Abnorm Social Psychol 1955;51:496–501.
[42] Gupta BS. Extraversion and reinforcement in verbal operant conditioning. Br J Psychol 1996;67:47–52.
[43] Gupta BS, Nagpal M. Impulsivity/sociability and reinforcement in verbal operant conditioning. Br J Psychol 1978;68:203–6.
[44] Gupta BS, Shukla AP. Verbal operant conditioning as a function of extraversion and reinforcement. Br J Psychol 1989;80:39–44.
[45] Nagpal M, Gupta BS. Personality, reinforcement and verbal operant conditioning. Br J Psychol 1979;70:471–6.
[46] Gupta S. Impulsivity/sociability and reinforcement in verbal operant conditioning: a replication. Personal Individual Differences 1990;11: 585–9.
[47] Zinbarg R, Revelle R. Personality and conditioning: a test of four models. J Personal Social Psychol 1989;57:301–14.
[48] Barratt ES. Psychophysiological correlates of classical differential eyelid conditioning among normal subjects selected on the basis of impulsiveness and anxiety. Biol Psychiatry 1971;3:339–46.
[49] Avila C, Parcet MA, Ortet G, Ibanez-Ribes I. Anxiety and counterconditioning: the role of the behavioural inhibition system in the ability to associate aversive stimuli with future rewards. Personal Individual Differences 1999;27:1167–79.
[50] Avila C. Sensitivity to punishment and resistance to extinction: a test of Gray's behavioural inhibition system. Personal Individual Differences 1994;17:845–7.
[51] Gray JA. Elements of a two-process theory of learning. London: Academic Press; 1975.
[52] Nicholson JN, Gray JA. Peak shift, behavioural contrast and stimulus generalisation as related to personality and development in children. Br J Psychol 1972;63:47–68.
[53] Seunath OM. Personality, reinforcement and learning. Percept Motor Skills 1975;41:459–63.
[54] Boddy J, Carver A, Rowley K. Effect of positive and negative reinforcement on performance as a function of introversion–extraversion: some tests of Gray's theory. Personal Individual Differences 1986;7:81–8.
[55] Derryberry D. Incentive and feedback effects on target detection: a chronometric analysis of Gray's model of temperament. Personal Individual Differences 1987;8:855–65.
[56] Avila C, Parcet MA. Individual differences in reward sensitivity and attentional focus. Personal Individual Differences 2002;33:979–96.

[57] Poy R, Eixarch M, Avila C. On the relationship between attention and personality: covert visual orienting of attention in anxiety and impulsivity. Personal Individual Differernces 2004; 36:1471–81.
[58] Gomez A, Gomez R. Personality traits of the behavioural approach and inhibition systems: associations with processing of emotional stimuli. Personal Individual Differences 2002;32:1299–316.
[59] Ball S, Zuckerman M. Sensation seeking. Eysenck's personality dimensions and reinforcement sensitivity in concept formation. Personal Individual Differences 1990;11:343–53.
[60] Hagopian LP, Ollendick TH. Behavioral inhibition and test anxiety: an empirical investigation of Gray's theory. Personal Individual Differences 1994;16:597–604.
[61] Hagopian LP, Ollendick TH. Behavioral inhibition and anxiety sensitivity: a reanalysis. Personal Individual Differences 1996;21: 247–52.
[62] McCord RR, Wakefield JA. Arithmetic achievement as a function of introversion–extraversion and teacher-presented reward and punishment. Personal Individual Differences 1981;2:145–52.
[63] Farrell M. The influence of reward/punishment and personality on pupil attainment. Personal Individual Differences 1997;22:825–34.
[64] Forlana G, Alexrod HC. The effect of repeated praise and blame on the performance of introverts and extroverts. J Educ Psychol 1937; 28:92–100.
[65] Thompson GC, Hunnicutt CW. The effect of repeated praise or blame on the work achievement of introverts and extroverts. J Educ Psychol 1944;35:257–66.
[66] Jackson C. Comparison between Eysenck's and Gray's models of personality in the prediction of motivational work criteria. Personal Individual Differences 2001;31:129–44.
[67] Gorenstein EE, Newman JP. Disinhibitory psychopathology: a new perspective and a model for research. Psychol Rev 1980;87:301–15.
[68] Patterson CM, Newman JP. Reflectivity and learning from aversive events: towards a psychological mechanism for the syndromes of disinhibition. Psychol Rev 1993;100:716–36.
[69] Wallace JF, Newman JP. Differential effects of reward and punishment cues on response speed in anxious and impulsive individuals. Personal Individual Differences 1990;11:999–1009.
[70] Newman JP. Reaction to punishment in extraverts and psychopaths: implications for the impulsive behaviour of disinhibited individuals. J Res Personal 1987;21:464–80.
[71] Avila C. Distinguishing BIS-mediated and BAS-mediated disinhibition mechanisms: a comparison of disinhibition models of Gray (1981, 1987) and of Patterson and Newman (1993). J Personal Social Psychol 2001;80:311–24.
[72] Avila C, Torrubia R. Personality, expectations, and response strategies in multiple-choice question examinations in University students: a test of Gray's hypotheses. Eur J Personal 2004; 18:45–59.
[73] Corr PJ. Testing problems in J.A. Gray's personality theory: a commentary on Matthews and Gilliland (1999). Personal Individual Differences 2001;30:333–52.
[74] Segarra P, Molto J, Torrubia R. Passive avoidance learning in extraverted females. Personal Individual Differences 2000;29: 239–54.
[75] Stelmack RM, Geen RG. The psychophysiology of extraversion. In: Gale A, Eysenck MS, editors. Handbook of individual differences: biological perspectives. New York: Wiley; 1992. p. 227–54.
[76] Bartussek D, Naumann E, Collet W, Moeller H. Ereigniskorreliertes Hirnrindenpotential (EKP) in Abhaengigkeit von der Rueckmeldebedeutung der Reize, Extraversion und Neurotizismus (Event-related cortical potentials (ERP) in relation to the significance of feedback stimuli, extraversion, and neuroticism). Trierer Psychologische Berichte 1990;17:1–56.
[77] Bartussek D, Naumann E, Moeller H, Vogelbacher D, Diedrich O. Emotionale Wortbedeutung, Extraversion, und der spaete positive Komplex des Ereigniskorrelierten Potentials (EKP) (Emotional content of words, extraversion, and the late positive complex of event-related potentials (ERP)). Paper presented at the 37th Congress of the German Psychological Society, Kiel; 1990.
[78] Bartussek D, Diedrich O, Naumann E, Collet W. Introversion–extraversion and event-related potential (ERP): a test of J.A. Gray's theory. Personal Individual Differences 1993;14:565–74.
[79] DePascalis V, Fiore A, Sparita AD. Personality, event-related potential (ERP) and heart rate (HR): an investigation of Gray's theory. Personal Individual Differences 1996;20:733–46.
[80] DePascalis V, Strippoli E, Riccardi P, Vergari F. Personality, event-related potential (ERP) and heart rate (HR) in emotional word processing. Personal Individual Differences 2004; 36: 873–91.
[81] Hagemann D, Naumann E, Lurken A, Becker G, Maier S, Bartussek D. EEG asymmetry, dispositional mood and personality. Personal Individual Differences 1999;27:541–68.
[82] Davidson RJ. Affective style and affective disorders: perspectives from affective neuroscience. Cogn Emotion 1998;3:307–30.
[83] DePascalis V, Speranza O. Personality effects on attentional shifts to emotional charged cues: ERP, behavioural and HR data. Personal Individual Differences 2000;29:217–38.
[84] Tellegen A. Structures of mood and personality and their relevance to assessing personality, with an emphasis on self-report. In: Tuma AH, Maser JD, editors. Anxiety and the anxiety disorders. Hillsdale, NJ: Erlbaum; 1995. p. 681–706.
[85] Larsen RJ, Katelaar T. Personality and susceptibility to positive and negative emotional states. J Personal Social Psychol 1991;61: 132–40.
[86] Gomez R, Cooper A, Gomez A. Susceptiblity to positive and negative mood states: test of Eysenck's, Gray's and Newman's theories. Personal Individual Differences 2000;29:351–65.
[87] Rusting C, Larsen RJ. Extraversion, neuroticism, and susceptibility to positive and negative affect: a test of two theoretical models. Personal Individual Differences 1997;22:607–12.
[88] Carver CS, White TL. Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: the BIS/BAS scales. J Personal Social Psychol 1994;67:319–33.
[89] Gable SL, Reis HT, Elliot AJ. Evidence for bivariate systems: an empirical test of appetition and aversion across domains. J Res Personal 2003;37:349–72.
[90] Torrubia R, Avila C, Molto J, Caseras X. The Sensitvity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ) as a measure of Gray's anxiety and impulsivity dimensions. Personal Individual Differerences 2001;31:837–62.
[91] Sanchez R, Torrubia R, Caseras X, Tobena A. Interrelationships between anxious personality and medical fears: an habituation study using exposure and benzodiazepine antagonists and agonists. Eur Neuropsychopharmacol 1995;5:376.
[92] Brandstatter H, Guth W. A psychological approach to individual differences in intertemporal consumption patterns. J Econ Psychol 2000;21:465–79.
[93] Corr, PJ, McNaughton N. Implications and extensions of J.A. Gray's behavioural inhibition system: a prolegomenon to the neuroscience of personality. In preparation.
[94] Blanchard DC, Hynd AL, Minke KA, Minemoto T, Blanchard RJ. Human defensive behaviors to threat scenarios show parallels to fear- and anxiety-related defense patterns of no-human mammals. Neurosci Biobehav Rev 2001;25:761–70.
[95] Matthews G, Gilliland K. Personality, biology and cognitive science: a reply to Corr (2001). Personal Individual Differences 2001;30: 353–62.
[96] Robinson DL. A commentary on Gray's critique of Eysenck's theory. Personal Individual Differences 1986;7:461–8.
[97] Corr PJ, Wilson GD, Fotiadou M, Kumari V, Gray NS, Checkley S, Gray JA. Personality and affective modulation of the startle reflex. Personal Individual Differences 1995;19:543–53.
[98] Corr PJ. J.A. Gray's reinforcement sensitivity theory and frustrative nonreward: a theoretical note on expectancies in reactions to

rewarding stimuli. Personal Individual Differences 2002;32: 1247–53.

[99] Gray JA, Corr P, Fotiadou M, Wilson G. Interactions between the behavioural inhibition and approach systems. Paper presented at the 23rd International Congress of Applied Psychology, Madrid, Spain; 1994.

[100] Corr PJ, Pickering AD, Gray JA. Personality and reinforcement in associative and instrumental learning. Personal Individual Differences 1995;19:47–71.

[101] Gray JA, Smith PT. An arousal decision model for partial reinforcement and discrimination learning. In: Gilbert RM, Sutherland NS, editors. Animal discrimination learning. London: Academic Press; 1969. p. 243–72.

[102] Corr PJ, Pickering AD, Gray JA. Personality, punishment, and procedural learning: a test of J.A. Gray anxiety theory. J Personal Social Psychol 1997;73:337–44.

[103] Corr PJ, Kumari V, Wilson GD, Checkley S, Gray JA. Harm avoidance and affective modulation of the startle reflex: a replication. Personal Individual Differences 1997;22:591–3.

[104] Zinbarg RR, Mohlman J. Individual differences in acquisition of affectively valenced associations. J Personal Social Psychol 1988;74: 1024–40.

[105] Jackson CJ, Francis LJ. Are interactions in Gray's Reinforcement Sensitivity Theory proximal or distal in the prediction of religiosity: a test of the joint subsystems hypothesis. Personal Individual Differences 2004; 36:1197–209.

[106] Corr PJ. J.A. Gray's reinforcement sensitivity theory: tests of the joint subsystems hypothesis of anxiety and impulsivity. Personal Individual Differences 2002;33:511–32.

[107] Avila C, Parcet MA. Personality and inhibitory deficits in the stop-signal task: the mediating role of Gray's anxiety and impulsivity. Personal Individual Differences 2001;31:975–86.

[108] Knyazev GG. Behavioural activation as predictor of substance use: mediating and moderating role of attitudes and social relations. Submitted for publication.

[109] Knyazev GG, Wilson GD. The role of personality in the co-occurrence of emotional and conduct problems in adolescents: a confirmation of Corr's 'joint subsystems' hypothesis. Personal Individual Differences 2004; in press.

[110] Harmon-Jones E. Anger and the behavioural approach system. Personal Individual Differences 2003;35:995–1005.

[111] DePascalis V, Arwari B, Matteucci M, Mazzocco A. Effects of emotional visual stimuli on auditory information processing: a test of J.A. Gray's reinforcement sensitivity theory. Submitted for publication.

[112] Gomez R, Cooper A, McOrmond R, Tatlow S. Gray's Reinforcement Sensitivity Theory: comparing the separable and joint subsystems hypotheses in the predictions of pleasant and unpleasant emotional informational processing. Personality and Individual Differences, 2004: in press.

[113] Kambouropoulos N, Staiger PK. Personality and responses to appetitive and aversive stimuli: the joint influence of behavioural approach and inhibition systems. Personality and Individual Differences, 2004: in press.

[114] Newman JP, Wallace JF, Schmitt WA, Arnett PA. Behavioural inhibition system functioning in anxious, impulsive and psychopathic individuals. Personal Individual Differences 1997;23:583–92.

[115] Van Yperen NW. On the link between different combinations of Negative Affectivity (NA) and Positive Affectivity (PA) and job performance. Personal Individual Differences 2003;35:1873–81.

[116] Carver CS, Sutton SK, Scheier MF. Action, emotion and personality: emerging conceptual integration. Personal Social Psychol Bull 2000; 26:741–51.

[117] Stable SL, Reis HT, Elliot A. Behavioral activation and inhibition in everyday life. J Personal Social Psychol 2000;78:1135–49.

[118] Benjamin J, Ebstein RP, Belmaker RH, editors. Molecular genetics and the human personality. Washington, DC: American Psychiatric Publishing; 2002.

[119] Canli T, Zhao Z, Desmond JE, Kang E, Gross J, Gabrieli JDE. An fMRI study of personality influences on brain reactivity to emotional stimuli. Behav Neurosci 2001;115:33–42.

[120] Amin Z, Constable RD, Canli T. Attentional bias for valenced stimuli as a function of personality in the dot-probe task. J Res Personal 2004;38:15–23.

[121] Reuter M, Stark R, Kirsch WP, Schienle A, Vaitl D, Hennig J. Personality and emotion: test of Gray's personality theory by means of an fMRI study. Behavioural Neuroscience, 118, 462–469.

[122] Caseras X, Avila C, Torrubia R. The measurement of individual differences in Behavioural Inhibition and Behavioural Activation Systems: a comparison of personality scales. Personal Individual Differences 2003;34:999–1013.