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REVIEW

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Varieties of impulsivity

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Abstract The concept of impulsivity covers a wide range of "actions that are poorly conceived, prematurely expressed, unduly risky, or inappropriate to the situation and that often result in undesirable outcomes". As such it plays an important role in normal behaviour, as well as, in a pathological form, in many kinds of mental illness such as mania, personality disorders, substance abuse disorders and attention deficit/hyperactivity disorder. Although evidence from psychological studies of human personality suggests that impulsivity may be made up of several independent factors, this has not made a major impact on biological studies of impulsivity. This may be because there is little unanimity as to which these factors are. The present review summarises evidence for varieties of impulsivity from several different areas of research: human psychology, psychiatry and animal behaviour. Recently, a series of psychopharmacological studies has been carried out by the present author and colleagues using methods proposed to measure selectively different aspects of impulsivity. The results of these studies suggest that several neurochemical mechanisms can influence impulsivity, and that impulsive behaviour has no unique neurobiological basis. Consideration of impulsivity as the result of several different, independent factors which interact to modulate behaviour may provide better insight into the pathology than current hypotheses based on serotonergic underactivity.

Key words Impulsivity · Personality · Serotonin · Behaviour

Introduction

Impulsivity is an aspect of behaviour which adds important colour to everyday life. Most people, at some time or another, have engaged in impulsive behaviour – such banal examples as taking one more drink, an extra purchase at the supermarket or just stopping and chatting to a friend met unexpectedly in the street. But, even if it is easy to identify examples of impulsive behaviour, there is considerably more difficulty in defining impulsivity precisely and there is likely to be a great deal of disagreement as to what differentiates socially acceptable impulsive behaviour from the unacceptable – that varies from one culture to another, from one era to another, and depends upon the age of the person involved. These differences do not usually matter so much for everyday life (except perhaps when cultures clash), but they do pose problems for the scientific study of impulsivity, and especially the study of the biological basis of that phenomenon.

A number of definitions of impulsivity and related concepts are listed in Table 1. Although I would not necessarily agree with everything contained in these, I think they support the main thesis which I would like to propound in this review. That is, that there is not one unitary "impulsivity" or only one type of impulsive behaviour. Instead, there are several related phenomena which are usually classified together as impulsivity, which I would like to term "varieties of impulsivity", and which lead to different forms of impulsive behaviour. Most importantly, these might be influenced by different biological mechanisms, thus rendering fruitless the search for a single biological basis of impulsivity. Support for this position comes from many psychological studies on human personality traits providing evidence that impulsivity is made up of several, independent factors coupled to qualitatively different aspects of behaviour. However, the impact of these results has been limited outside their field of origin. The majority of human clinical studies or neurobiological studies in non-human subjects adopt an ostensibly atheoretical (intuitive?) approach, which appears to assume that impulsivity is a monolithic whole even when employing techniques perhaps more suited to a multifactorial view of impulsivity. Unfortunately, with a few exceptions, researchers interested in the personality trait of impulsivity, in the experimental analysis of im-

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Table 1 Definitions

Definitions taken from three medical dictionaries:
"*Impulse*: a sudden urge to act in response to subjective or external stimuli: used especially of behaviour viewed as powerfully motivated, compulsive or irrational." (Churchill's Medical Dictionary 1989)
"*Impulsion*: blind obedience to internal drives without regard for acceptance by others or pressure from the superego: seen in children and adults with weak psychic organisation." (Dorland's Illustrated Medical Dictionary 1994)
"*Impulsive*: relating to or activated by an impulse rather than controlled by reason or careful deliberation." (Stedman's Medical Dictionary 1995)

And one from a recent book reviewing research on impulsivity:
"The behavioural universe thought to reflect impulsivity encompasses actions that appear poorly conceived, prematurely expressed, unduly risky, or inappropriate to the situation and that often result in undesirable consequences" (Daruna and Barnes 1993, p. 23)

pulsive behaviour, in psychiatric studies of impulsivity or in the neurobiology of impulsivity form largely independent schools, who rarely cite one another's work, and consequently rarely gain any insight into their own work from the progress made by others. One goal of this review is to attempt to counteract that tendency.

Although the focus of my own research has been exclusively behavioural pharmacological using non-human subjects, to place the results of such studies in a framework relevant to human behaviour, it is necessary to understand some of the terms and concepts from human personality research and psychiatry. I have therefore chosen to start by reviewing this background material before moving on to animal studies, and to specific studies in behavioural pharmacology. In this way, it is possible to demonstrate that the varieties of impulsivity fractionated using pharmacological tools have close parallels in normal and pathological human behaviour.

It is also important to separate impulsivity per se from the types of behaviour which may be influenced by impulsivity. Many studies have been carried out to examine neurobiological influences on aggressive behaviour or drug addiction in which alterations in impulsivity have been implicated. However, the methods employed have rarely been such that it is possible to ascertain whether the factor under study is having a direct effect on the target behaviour, or whether it is having an indirect effect via impulsivity. Furthermore, there have been few attempts to see whether factors influencing for example, impulsive aggressive behaviour, can also influence other forms of impulsive behaviour, particularly those lacking an aggressive component, in a similar manner. The current upsurge of interest in impulsivity suggests that this situation will soon be remedied. For example, Brunner and Hen (1997) compared the behaviour of 5-HT_{1B} receptor knockout mice in tests of aggression and drug self-administration, but also in delay of reinforcement and timing procedures, tests, as they put it, of cognitive impulsivity.

Impulsivity and personality

There is a methodological tradition of studying human personality by applying factor analysis to the responses made to questionnaires, to examine whether the variability in the answers can be accounted for by one or more statistical factors. In principle, no assumptions should be made about how many factors are involved, but there is always some risk that the researcher's own opinions are reflected in the nature of the questions posed. As questions are added or deleted over a long period of research, the factors emerging from the analysis may change. This does not mean that human personality has changed but rather that the study materials do not adequately capture the complexity of what is being studied. Nearly all of this work provides evidence of multiple varieties of impulsivity (see Table 2 for a summary).

Dickman (1990) has distinguished two different types of impulsivity: dysfunctional impulsivity defined as the tendency to act with less forethought than do most people which leads the subject into difficulties ("Often I don't spend enough time thinking over a situation before I act"), and functional impulsivity, that is the tendency to act with little forethought when the situation is optimal ("I am good at taking advantage of unexpected opportunities where you have to do something immediately or lose your chance"). These two types of impulsivity appear to be unrelated. Dickman's results illustrate an important issue which is often overlooked – not all impulsive behaviour is disadvantageous. Indeed, one might wonder how obviously impulsive patterns of behaviour have remained intact through evolutionary history if they are as pathological as is sometimes assumed. Dickman has also reviewed evidence for the involvement of cognitive processes in impulsivity (Dickman 1993), and proposed that differences in impulsivity between individuals may reflect differences in the mechanisms which allocate attention. Even though impulsive individuals claim to act with less forethought, they often respond more slowly in experimental tasks than non-impulsive individuals (e.g. Dickman 1985). Perhaps highly impulsive individuals actually spend less of that preparation time focusing on the task in hand. Low impulsives are superior on tasks which require fixation of attention, whereas Dickman suggests that high impulsives could potentially perform better on tasks where attention needs to be switched rapidly. However, Dickman (1993) also identified two aspects of impulsivity which he explicitly omitted from his analysis. The first of these was "reflection-impulsivity", measured by the matching familiar figures test (MFFT; Kagan 1966). This exclusion is surprising, since "reflection-impulsivity" would seem to involve attention. In explanation, Dickman suggests that "reflection-impulsivity" must be a separate dimension, since results on the MFFT do not correlate with either self-report or other behavioural measures of impulsivity (this criticism has been reviewed by Block et al. 1974). Second, Dickman also excludes syndromes of disinhibition (Newman 1987), as evidenced for example, by an increased num-

Table 2 Varieties of impulsivity proposed by various researchers working mainly with human subjects cited in the text with definitions or examples. *APA* American Psychiatric Association, *BIS* Barratt Impulsiveness Scale, *DSM IV* Diagnostic and Statistical Manual of Mental Disorders (4th edn) *IRS* Impulsivity Rating Scale

Dickman (1990)	Dysfunctional impulsivity	The tendency to act with less forethought than most people of equal ability when this tendency is source of difficulty
	Functional impulsivity	The tendency to act with relatively little forethought when such a style is optimal
Dickman (1993)	Attentional	Insufficient focusing of attention leads to impulsivity
	"Reflection-impulsivity"	As measured by the matching familiar figures task (Kagan 1966)
	Disinhibition	Failure to withhold responses often leading to omission of reward (Newman et al. 1985)
Buss and Plomin (1975)	Inhibitory control	Example – I have trouble controlling my impulses, usually I can't stand waiting
	Decision time	Example – I often say the first thing that comes into my head, or act on the spur of the moment
	Lack of persistence	Example – I tend to give up easily, I tend to hop from interest to interest quickly
	Boredom/sensation seeking	Example – I generally seek new and exciting experiences and sensations, I get bored easily
Eysenck (1993)	Impulsiveness	Unconscious risk taking
	Venturesomeness	Conscious sensation seeking
BIS-10 (Patton et al. 1995)	Motor	Acting without thinking
	Cognitive	Making quick cognitive decisions
	Non-planning	Present orientation or lack of "futuring"
BIS-11 (Barratt 1994)	Ideomotor	Acting without thinking
	Careful planning	Paying attention to details
	Coping stability	Orientation towards the future
Tridemensional Personality Questionnaire (Cloninger 1987)	Novelty seeking	Example – acts immediately on momentary whims*
	Harm avoidance	Example – carefree lack of inhibition even when the situation calls for attention*
	Reward dependence	Example – lack of persistent ambition for delayed rewards*
Karolinska Scales of Personality (Schalling 1987)	Impulsiveness	Example – I have a tendency to act on the spur of the moment *
	Irritability	Irritable, lacking in patience
IRS (Lecrubier et al. 1995)	"Self-control"	In normals weighting irritability, aggressivity and control of responses
	Time needed for decision	In normals weighting time needed for decision and capacity for delay
DSM IV (APA 1994) Substance abuse disorders		Example – persistent desire or unsuccessful efforts to cut down or control substance abuse
		Example – great deal of time spent in activities necessary to obtain the substance
DSM IV (APA 1994) Attention deficit/ hyperactivity disorder	Inattention	Example – often has difficulty in sustaining attention in tasks or play activities*
	Hyperactivity	Example – often leaves seat in classroom or situations in which remaining seated is expected*
	Impulsivity	Example -often blurts answers before questions have been completed*
DSM IV (APA 1994) Mania	Criterion 7	Excessive involvement in pleasurable activities that have a high potential for painful consequences

*See text for more examples

Table 3 Examples of statements from the Barratt Impulsivity Scale (BIS)

ber of incorrect "go" responses in a go/no-go discrimination test (Newman et al. 1985). Thus, within dysfuntional impulsivity, Dickman identifies at least three separate dimensions – attentional, reflection-impulsivity, disinhibition.

H. J. Eysenck is best known for identifying three dimensions of personality, Extraversion, Neuroticism and Psychoticism (Eysenck and Eysenck 1985), based upon self-report questionnaires. Eysenck found that items which intuitively reflected impulsivity are often associated with different personality factors on the Eysenck personality questionnaire, both Psychoticism and Extraversion. He notes (Eysenck 1993) that there is a difference between postulating the existence of a trait and demonstrating it psychometrically, which has not been an easy task in the case of impulsivity. A new questionnaire, finally called the I_5 (Eysenck S. G. B. 1993) was constructed which led to the identification of a two-factor solution where one of the factors was labelled Impulsiveness (Imp), and a second, Venturesomeness (Vent).

Eysenck S. G. B. (1993) differentiated these two items in the following way: “Our concept of Imp and Vent can best be described by analogy to a driver who steers his car around a blind bend on the wrong side of the road. A driver who scores high on Imp never considers the danger he might be exposing himself to and is genuinely surprised when an accident occurs. The driver who scores high on Vent, on the other hand, considers the position carefully and decides consciously to take the risk”...(Eysenck S. G. B.1993, p. 144). As Eysenck S. G. B. (1993) points out, “both Imp and Vent factors are routinely thought of by lay-persons as ‘impulsivity’. However, they are relatively independent and represent largely different behaviours”. H. J. Eysenck has also been influential in a second way, via his theory that Extraversion, and by extension, impulsivity, are caused by low cortical arousal (Eysenck 1967). This theory, even if controversial, and Eysenck himself admits it does not cover all of the data (Eysenck 1993), has inspired many studies, since arousal is relatively easy to manipulate in human volunteers without the recourse to pharmacological interventions.

A second line of research which has a long history of incremental development is that carried out by Barratt and colleagues. The Barratt Impulsiveness Scale (BIS), which has gone through several versions, was initially developed to separate impulsiveness from anxiety. The goal of the research of Barratt and his colleagues was three-fold: “(1) to describe impulsiveness in ‘normal persons, (2) to arrive at the role of impulsiveness in psychopathology, and (3) to develop a personality framework within which impulsiveness as a personality trait could be related to other traits” (Barratt 1994, p. 63). Barratt states that he and his colleagues have been aware of the shortcomings of self-report scales, for example, the question of the ability of patients with impulsivity problems to assess their own cognitive functions, but offers little in the way of alternatives. Some examples of the statements to be rated are can be found in Table 3. As the scale has developed, so the number of subscales and the factorial results of the analysis have varied. For example, BIS-7B had five sub-scales – sensory stimulation, motor impulsivity, interpersonal behaviour, self-assessment of impulsivity and risk taking (Barratt and Patton 1983). Analysis of the BIS-10 lead to three second-order factors: attentional impulsiveness, motor impulsiveness and non-planning impulsiveness (Patton et al. 1995). Barratt (1994) suggests that there are three subtraits in the BIS-11 item pool: an “ideomotor” impulsiveness, involving acting without thinking, a “careful planning” subtrait involving attention to details, and a future orientated “coping stability” subtrait. Motor impulsivity and planning-related impulsivity have been consistently identified as dimensions in the successive versions of the BIS, although it is the more recently defined trait of “coping stability” which seems to differentiate most between “normals” (i.e. college students) and patients with psychopathology (Barratt 1994). There are numerous examples where the BIS has been included in the battery of self-report questionnaires in psychiatric studies. However, since impulsivity is usually not the main focus of the study and the results are negative, it is, unfortunately, often difficult to extract the results without detailed reading.

I am restless at theatre or lectures
I buy things on impulse
I make up my mind quickly
I am more interested in the present than the future

Table 4 The statements from KSP impulsivity scale (translated from Swedish by J. L. E.)

Other authors have assumed from the start that impulsivity is multifactorial. For example, Buss and Plomin (1975) concluded that “impulsivity consists of more than one dimension of control” and considered that inhibitory control lies at the core of impulsivity, but that decision time, persistence and boredom or sensation seeking are other important aspects of impulsivity They found statistically significant, but not very high correlations (0.14–0.34) between the four aspects they identified using a small number of targeted questions in a sample of the parents of twins (Buss and Plomin 1975).

Impulsivity in psychiatry

Most of the material described above has been developed on the basis of variations in “normal” human personality, even if, in some cases, extrapolations have been made to certain pathological populations, usually not very well defined. However, there are also approaches to measuring impulsivity which have been specifically designed to assess pathological impulsivity.

Undoubtedly the most influential personality construct theory in psychiatry today is that of Cloninger (1987), who proposed a unified biosocial theory of personality, postulating that there are three dimensions of personality that are genetically independent, called Novelty seeking, Harm avoidance and Reward dependence. Assessment of these has been formalised into the Tri-dimensional Personality Questionnaire, which has been used quite extensively in clinical studies where personality has been proposed to play an important role. Cloninger (1987) sought to show that these three dimensions reflect variations in certain major neurotransmitter systems. This proposal was based primarily upon data from animal studies. Novelty seeking is proposed to relate to activity in the dopaminergic “reward system”, Harm avoidance to activity in a serotonergic “punishment” system, and Reward dependence to the influence of noradrenaline on the association of conditioned signals of reward or punishment. Challenging though this speculation is, good clinical or basic support for a coupling of these personality traits to the specified biological mechanisms is still lacking.

It is important to note that Cloninger´s system has no factor which corresponds to impulsivity. Instead, charac-

teristics which usually considered as impulsive are spread across the three personality dimensions. Within high novelty seeking are found characteristics such as "acts immediately on momentary whims" or "extravagant spending so has difficulty saving or delaying gratification". Low harm avoidance contains the characteristic "carefree lack of inhibition even when the situation calls for attention" and "overconfident and lacking in appropriate caution when dealing with unfamiliar tasks". Low reward dependence can be characterised as "frequently quitting before maximal effort has been expended", "frequent termination of activities that are not immediately gratifying" and "lack of persistent ambition for delayed rewards" (Cloninger 1987, p. 582). These are only some of the many characteristics of the extremes of these dimensions. It would be wrong to associate any of these extremes with impulsivity in the conventional meaning. Antisocial personality disorder, for example, is characterised by high novelty seeking, low harm avoidance and low reward dependence: all three containing elements of impulsive behaviour. Unfortunately, not even Cloninger's system has remained immutable. First, a fourth dimension of Persistence emerged from normative data (see Cloninger et al. 1993), this too having an obvious component relating to impulsivity, and finally three new dimensions, termed character dimensions, have been added recently: Self-directedness, Cooperativeness and Self-transcendence (Cloninger et al. 1993).

Another approach to assessing impulsivity in the clinic is provided by the Karolinska Scale of Personality (KSP), and Lecrubier's Impulsivity Rating Scale. The KSP was developed with the express purpose of defining aspects of temperament which might be related to vulnerability for different forms of psychopathology (Schalling et al. 1987). Although this scale has been applied to a wide range of populations, including many non-psychiatric patient groups, it does not seem to have been widely used outside of its country of origin, Sweden. The statements from the impulsivity scale are shown in Table 4. High scorers are described as acting on the spur of the moment, non-planning and impulsive. Impulsiveness is included in a sub-scale grouped with monotony avoidance and detachment, and perhaps reflects a more narrow definition than usual. In contrast, subjects who are irritable and lacking in patience would be expected to score high on the irritability scale, included in the group of aggression-related scales. Although this division may seem somewhat artificial from some perspectives, it represents an attempt to separate impulsivity and aggressive behaviour, which are often confounded in psychiatric studies.

Lecrubier and colleagues (Lecrubier et al. 1995) noted in the majority of cases that impulsivity ratings depend upon either extracting items from non-specific rating scales or personality inventories which can be administered by an assessor, or using specific self-rating scales which are filled in by the patient. In general, it may also be easier for an independent rater to assess the current state of the patient separately from the underlying, long-term, personality traits. Furthermore, some types of patient may be poor at assessing their own status (or at least at variance with external raters; Mattila-Evenden et al. 1996). This distinction may be important for monitoring the progress of a therapeutic intervention, for example. Lecrubier et al. (1995) developed a scale which can be used by a clinician to rate patients consisting of seven items, which they have called the impulsivity rating scale (IRS). The seven items are: irritability, patience-impatience, time to make decisions, capacity to pursue an activity, aggressiveness, control of responses and capacity to delay. Principle component analysis on a relatively small sample of subjects suggested that the two items "time needed for decision" and "capacity for delay" might belong to a separate factor than the other five items.

I have a tendency to act on the spur of the moment, without thinking about it so deeply
I often sleep on something before I decide (scored negatively)
I get very enthusiastic about new ideas and suggestions that I forget to find out if there are any disadvantages
It often happens that I get involved in things a little too hastily
I am very careful (scored negatively)
I can be described as a person who takes each day as it comes
I usually speak first and think afterwards
When I have made up my mind things generally happen quickly
I take life easily
I consider myself impulsive

Given the widespread incidence of impulsive behaviour in psychiatric syndromes, it is of no surprise that several of the disorders classified by the DSM IV system (Diagnostic and statistical manual, 4th edition; APA 1994) also contain elements of impulsivity in their diagnostic criteria. The DSM system is not for the most part concerned with the minutiae of specific symptoms, rather with providing physicians with useful "rule-of-thumb" guidelines for obtaining a differential diagnosis. Impulsivity or impulsive behaviour does not appear as a separate syndrome in the DSM system, but may be featured as one of several, qualitatively different types of behaviour, which when clustered together, lead to the assignment of a particular diagnosis. The adult psychiatric disorders most associated with impulsive behaviour are mania, substance abuse and the personality disorders. Of these, the diagnostic criteria for substance abuse disorders are the most illuminating when it comes to varieties of impulsivity. Amongst the criteria are the following items:

i. The substance is often taken in larger amounts or over a longer period than was intended.
ii. There is a persistent desire or unsuccessful efforts to cut down or control substance abuse.
iii. A great deal of time is spent in activities necessary to obtain the substance (e.g. visiting multiple doctors or driving long distances).

iv. The substance use is continued despite knowledge of having a persistent or recurring physical or psychological problem that is likely to have been caused or exacerbated by the substance.

Whereas (i), (ii) and (iv) are obvious examples of impulsive behaviour (or if you like, a breakdown in impulse control), item (iii) emphasises another aspect of the behaviour of the substance abuser which cannot be described as impulsive – the great amount of planning and effort which goes into obtaining the substance. The strategies which addicts use to cover up their continued abuse to hide it from employers, spouses and treating personnel can also be elaborate and well-planned. Impulsive behaviour would be counter-productive. Thus to develop into a disorder which is serious, malignant and difficult to treat, substance abuse disorder must consist of two components -poor impulse control when it comes to assessing the dangers of the substance abuse, coupled to very good impulse control when it comes to feeding and hiding the abuse.

A second type of psychiatric disorder where varieties of impulsivity are evident is attention deficit/hyperactivity disorder (ADHD). As the name suggests, according to the DSM IV definition of this disorder, attention deficit and hyperactivity can occur independently or together. The diagnostic criteria related to impulsivity in the definition are “often blurts answers before questions have been completed”, “often has difficulty in awaiting turn” and “often interrupts or intrudes onto others”. However, other items defined in the criteria as inattention (e.g. “often has difficulty in sustaining attention in tasks or play activities” or “often does not follow through on instructions and fails to finish schoolwork, chores or duties in the workplace”) or hyperactivity (e.g. “often leaves seat in classroom or in other situations in which remaining seated is expected”) seem equally well to fall within a broad definition of impulsivity. In other words, the psychiatrists who wrote the diagnostic criteria appear to have chosen to divide up a general behaviour pattern characterised by widespread impulsivity into sub-sets of criteria termed “inattention”, “hyperactivity” and “impulsivity” which still have much in common, but may occur independently of one another.

In summary, the majority of researchers in the area of normal or pathological human personality acknowledge that there are different varieties of impulsivity. However, they are not always in agreement where the dividing lines fall. Nonetheless, it is evident that different aspects of impulsivity appear to be important in different psychiatric syndromes.

Impulsivity: behavioural approaches

In addition to the preceding approaches to measuring impulsivity based largely on introspection and self-report, there are a number based upon the assessment of impulsive behaviour. These have the advantages that they can be used to study the behaviour of both animal and human subjects.

Behavioural inhibition

A significant step in developing modern integrated research in impulsivity was taken by Soubrié (1986). The key element of his review was to try to unite findings from the behavioural pharmacology of manipulations of the serotonergic systems in animals and clinical evidence for a role of serotonin in the control of behaviour. Soubrié reviewed the effects of drugs which increase or decrease serotonergic neurotransmission (including neurotoxic destruction of the serotonergic systems) on behaviour suppressed by punishment or by novelty, and behaviour inhibited by non-reward. Drugs or other treatments which decreased serotonergic neurotransmission tended to attenuate punishment-induced suppression of behaviour. This has often been taken as evidence of an anxiolytic effect, although this type of manipulation has rarely if ever been found to reduce anxiety in humans. Likewise, manipulations decreasing serotonergic function tend to attenuate novelty-induced suppression of behaviour, for example, feeding or social behaviour. Conversely, drugs which increase serotonergic transmission generally enhance punishment-induced inhibition where this is not already maximally suppressed by the punishment contingency. Finally, the involvement of serotonergic neurones in the control of behaviour under conditions of non-reward seems to involve the animal’s level of control over reward delivery or its level of reward expectancy. On the basis of these data, Soubrié (1986) concluded that “serotonergic neurones are brought into play whenever behavioural inhibition is required or an overt conflict emerges between making or Go, and refraining, or No-Go, response contingencies.” A decrease in serotonergic transmission renders animals less able to adopt passive or waiting attitudes. Soubrié (1986) was especially concerned to separate this response facilitation from perseveration. For example, raphé-lesioned animals show increased locomotor activity in an open field but a greater change in their behaviour in response to introduction of a novel object (Srebro and Lorens 1975), i.e. the effect is context dependent, or that serotonin antagonists reduce a form of neurochemically induced perseverative behaviour, apomorphine-induced stereotypies, whereas serotonergic agonists have the opposite effect (Carter and Pycock 1978). In the final section of the review, Soubrié (1986) summarised the data available up to that time relating low levels of cerebrospinal 5-hydroxyindoleacetic acid (5-HIAA, the main metabolite of serotonin) to aggressive suicidal behaviour, violence, obsessive compulsive behaviour and alcoholism – all disorders in which the patients with low CSF 5-HIAA levels have difficulty in integrating drives and impulses. Subsequent research has extended these findings considerably. For example, Linnoila and colleagues have carried out a series of studies examining serotonergic markers in vio-

lent aggressive individuals and alcoholics. They found (Linnoila et al. 1983) that CSF 5-HIAA was reduced only in individuals where the aggression was impulsive rather than those in whom it was premeditated. Low CSF 5-HIAA is primarily associated with impaired impulse control, whereas high CSF free testosterone concentration is associated with aggressiveness (Linnoila et al. 1993). Adolescent male rhesus macaques with low CSF 5-HIAA concentrations have been found to exhibit more violent forms of aggressive behaviour and make longer and more risky leaps during movement through the forest (Mehlman et al. 1994).

Our knowledge of the serotonin system has increased immensely since the time when most of the studies referred to by Soubrié were carried out. In the last decade since the publication of his review, molecular biology has helped to identify several novel serotonergic receptors which modulate and mediate the activity of the serotonergic systems. As mentioned above, at least one of these receptors, the 5-HT_{1B} receptor, as specifically been coupled to impulsivity, since mice lacking this receptor have been described as showing greater motor impulsivity (Brunner and Hen 1997). Considerable effort has been made to develop agents which act selectively via these mechanisms providing tools which are of great help to pre-clinical behavioural pharmacology. Nevertheless, the basic tenets of Soubré's review have been well accepted in current thinking about the role of serotonin on behaviour, particularly in psychiatry. His hope in the last sentence of the review that evidence from the use of selective serotonergic reuptake inhibitors in "various forms of impulsivity (bulimia, alcoholism, obsessive-compulsive disorders)" might strengthen his hypothesis has been fulfilled at least to some extent. In bringing together diverse data, generating ideas and stimulating further successful research, some of which has been carried out by Soubrié himself with colleagues (Thiebot et al. 1985; Bizot et al. 1989), this review has been an important and productive catalyst.

The Matching Law and delay of reinforcement

The first chapter of a book titled "Self-control: waiting until tomorrow for what you want today", by Logue (1995) begins as follows: "People often do things that result in some immediate gratification, but which in the long run are not very beneficial....Engaging in such behaviours...can be termed impulsiveness." While admitting that this might not satisfy everyone, the approach taken by Logue and like-minded researchers has been to consider self-control (the inverse of impulsivity) as a function of factors controlling the choice of delayed reinforcers (Logue 1988; Rachlin 1995). In other words, impulsivity has been transformed into a problem with the ability to delay gratification The advantages of doing this are primarily practical – delay of reinforcement is easily defined in the laboratory, it can be examined in both humans and other species – while it also encompasses quite a lot of frequently exhibited human behaviour (Logue 1988). The implication is that impulsivity is a unitary phenomenon. Logue (1988) suggests that much of the data on delay of reinforcement can be explained by the two dominant models in the experimental analysis of behaviour. The first, Herrnstein's matching law (Herrnstein 1970), provides a quantitative model of response choice:

$$B_L/B_R=A_LD_R/A_RD_L \quad (1)$$

where B_L and B_R are the rates of the two behaviours in question, A_L and A_R the amount of the reinforcer contingent upon each behaviour, and D_L and D_R the delays associated with each reinforcer. The second model, derived from research on optimal foraging, emphasises the amount of energy gained by engaging in different forms of behaviour. In this case "energy gain" replaces (A) amount in Equation (1) and "handling time" replaces (D) delay. Energy gain/handling time is seen as an index of profit. In both cases, the probability that a subject will choose a smaller reinforcer delivered after a short delay rather than a larger reinforcer after a longer delay is a direct function of the relative size of the reinforcers and an inverse function of their relative delays and incorporates the principle that the efficacy or "value" of a reinforcer decreases a function of the delay which precedes its delivery. Often, these functions are assumed to be hyperbolic. Logue (1988) also provides examples where this basic rule can be over-ridden, for example, using a long "fading procedure" in which an initial delay associated with the smaller reinforcer was gradually eliminated led to a greater selection of the delayed reinforcer than would otherwise be expected (Mazur and Logue 1978) or using pre-commitment, in which the first choice is between a path which leads a second response delivering a large reinforcer after a delay, or a path which leads to a second choice between a large delayed and small immediate reinforcer (e.g. Rachlin and Green 1972). Again, there is greater selection of the larger reinforcer than is usually the case. To account for this behaviour, Logue et al. (1984) introduced extra exponential parameters into Equation 1 to capture the subject's sensitivity to the relative variation in the amount and delay of the alternative reinforcers.

$$B_L/B_R=k(A_L/A_R)^{S_A}(D_R/D_L)^{S_D} \quad (2)$$

In this equation there are now two independent factors influencing response choice which can be considered to relate to impulsivity – the delay associated with the reinforcer and the sensitivity of the animal to that delay. Logue (1988) comments that as this and other similar models move away from describing behaviour as a function of current measured characteristics of the reinforcer, they become capable of describing more data, but at the same time harder to disprove and the predictiveness of the models is not necessarily improved. Logue notes that both models would predict that any manipulation that

would make time to reinforcement seem to go faster should increase self control (and conversely, manipulations which make time go slower should lead to increased impulsivity). A similar hypothesis has been proposed by Barratt (1983) to explain the impulsivity of human subjects.

Behavioural timing

Van den Broek and colleagues have provided a couple of examples on how this "timing" hypothesis can be approached empirically. In the first of their studies (van den Broek et al. 1987), impulsive and non-impulsive human subjects, categorised using the MFFT, were tested using a procedure in which they were asked to space responses by at least 10 s (inter-response time (IRT) >10, also known as DRL-10). The presence of a cue light and instructions were varied in four phases. Impulsive subjects consistently earned fewer reinforcers than non-impulsive subjects in the absence of a cue and explicit instructions due to emission of a higher proportion of short IRTs, although both groups performed near optimal when explicit information about the cue light was presented. However, there are several different possible explanations for this deficit, not all of which involve timing. In their second study (van den Broek et al. 1992), impulsive and non-impulsive subjects were tested on a time reproduction task and a time comparison task. In the time reproduction task, the impulsive subjects tended to produce a time which was too short. The impulsive subjects were also poorer at discriminating time intervals, although this might have reflected a lower IQ score in that group. Thus it does appear that impulsive subjects have a problem in evaluating the passage of time, and that for them subjective time does seem to pass more slowly, which might then lead to the behavioural deficits identified.

The same research group, Bradshaw and colleagues, have also been carrying out a series of experiments investigating the neurobiological basis of timing in rats (reviewed by in Ho et al. 1998), testing the hypothesis that the serotonergic systems could affect impulsivity by altering timing functions. They have done this by studying the effects of destruction of the ascending serotonergic innervation of the brain (using the selective neurotoxin 5,7-DHT) on procedures explicitly designed to measure timing. As noted above, this should, in turn, affect performance in many procedures testing impulsivity, such as delay of reinforcement, DRL etc., since they are crucially dependent on the animals accurately registering the passage of time or the relative value of two temporal intervals. The procedures they used included the fixed-interval peak procedure (Morrisey et al. 1994), the interval bisection procedure (Morrisey et al. 1993; Graham et al. 1994; Ho et al. 1995), tests of temporal differentiation and temporal discrimination, respectively (i.e. the same tests as employed in the human studies). The conclusion drawn from these studies was that loss of CNS 5-HT impaired acquisition and coarsened temporal control in the temporal differentiation schedule, but did not impair and perhaps improved performance in the interval-bisection task. Ho et al. (1998) conclude that although 5-HT loss "impedes the animals' ability to regulate their own behaviour in time, it does not impair their ability to make precise temporal discrimination" and thus does not reflect "a disturbance of those processes that are considered fundamental to current models of timing". Instead, further work with a free-operant psychophysical test (Al-Zahrani et al. 1996) suggested that loss of CNS 5-HT markedly increased the rate of switching between two response alternatives. This hypothesis bears some resemblance to that proposed by Dickman (1993) regarding focusing of attention, referred to above. Ho et al. conclude that "behavioural 'switching' is a promising candidate for a process whose impact is felt in at least some of the behavioural tasks relevant to the 'impulsiveness' construct, and which appears to be highly sensitive to lesions of the serotonergic pathways". Again, the data suggest the operation of at least two processes which may contribute to impulsive behaviour: timing and switching.

Impulsivity as a multifactorial phenomenon

My own work on impulsivity started from the premise that the phenomenon is multifactorial. During our work using the DRL-72 schedule as an empirical screen for novel, potential antidepressant agents (Evenden et al. 1993), my colleagues and I realised the key factors controlling DRL performance and performance in delay of reinforcement procedures (for example, the one used by Bizot et al. 1988) are quite different, although both DRL and delay of reinforcement procedures could be described as tests of impulsivity in a broad sense. In the DRL procedure, the behaviour of the animal during the delay has an important influence on whether or not the reinforcer is delivered. On the other hand, in a delay of reinforcement procedure, once the subject has made the choice the outcome is already decided, whatever it does during the delay. Furthermore, the relationship between the response and the outcome is much more subtle in a delay of reinforcement procedure than in DRL. In the DRL, when the animal responds either the reinforcer is delivered immediately or not at all – an all-or-none event. In a delay of reinforcement procedure, often nothing at all happens when the animal responds, other than that further responding is hindered in some way. The outcome of the response only becomes evident some time later, and is then the difference in the magnitude between the small and large reinforcers – a matter of degree. In other words, in the DRL-72 procedure organisation of motor behaviour is of primary importance, in the delay of reinforcement procedure, the ability to assess subtle differences in the outcome of behaviour is at a premium, and the requirements for the organisation of motor performance are minimised. This insight led us to question the assumption that impulsivity was unitary and to begin a series of studies designed to test the possibility

that impulsivity was multifactorial using psychoactive drugs as the dissection tools.

One of the key requirements of the methods was to eliminate influences from drug-induced activation or sedation by using choice procedures rather than procedures based upon the rate of responding. For example, since the indices of impulsivity provided by both DRL and conventional free operant FCN schedules are sensitive to confounding by drug-induced disruption of behaviour, instead of the DRL-72, a paced fixed consecutive number (FCN) procedure was developed. In the paced FCN test (Evenden 1998b) the rat had to complete a chain of at least eight responses on one lever before responding on a second to deliver food. If the chain was longer than eight responses when it was terminated, then there was no additional penalty, but if it was shorter than eight responses, then there was a brief time out and the rat was required to start a new chain. The time taken to complete the chain was controlled by the experimenter, by retracting the response levers for a brief interval after each response. A longer interval between responses led to a shorter mean chain length.

The effects of drugs on the sensitivity to delay of reinforcement reported by Thiebot et al. (1985) and Bizot et al. (1988) were obtained using a maze-procedure. Such procedures are generally very time consuming, and I and my colleagues felt there was a need to automate the "Thiebot" method. Furthermore, we felt there was a need to vary the delay of reinforcement during each test session to obtain a choice/delay function which could be altered by the drugs acutely. We therefore devised a method (Evenden and Ryan 1996) in which rats are trained to choose between one lever always providing one food pellet, and another lever always providing several pellets (five in most experiments). In the absence of delays, the rats respond almost exclusively on the lever providing several food pellets (the larger reinforcer). By dividing the session into discrete trials of a fixed length, and stepping up the delay between the lever press and delivery of the large reinforcer over blocks of 8–12 trials, we could demonstrate a shift in preference during every test session, so that by the end of the session, when the delay was 60 s long, most rats still responded, but now showing a preference for the small, immediate reinforcer. Sensitivity to the delay of reinforcement could be demonstrated simply by programming longer or shorter delays on test days, and recording a shift in preference.

In addition, an important feature of impulsivity was not adequately captured by the paced FCN and delay of reinforcement procedures. The need to collect information and reflect upon it before making the decision, the "reflection-impulsivity" of Kagan (1966), was missing. To capture this aspect of impulsivity, it was necessary to design a test where the relationship between the time taken to prepare to make a response and the likely outcome of the response were explicitly related. A visual discrimination was used in which a flashing light "jumped" between two levers. The likelihood that it stayed above the lever delivering food increased over a period of 5–6 s. An immediate response gave the rat a 50/50 chance of obtaining food. If it waited 5–6 s, then it could use the information provided by the light to make 100% correct responses. In this way, the rat had a better chance of obtaining food if it waited before responding. These three procedures provided three apparently independent scores of impulsivity, which appear to reflect different aspects of the way it can influence behaviour, i.e. different varieties of impulsivity.

1. RT distribution and accuracy in the uncertain visual discrimination test – preparation to respond.
2. Mean chain length and chain length distribution in the paced fixed consecutive number test – execution of the behaviour.
3. Preference for the larger reinforcer over a series of delays from 0 to 60 s – assessment of outcome.

Drug effects on varieties of impulsivity

Once these methods had been established, the effects of a series of psychoactive drugs were tested, especially concentrating on those having actions on the serotonergic systems. The results of some of the key drugs are summarised in Table 5, based upon the findings report-

Table 5 The effects of a number of drugs in the three tests of impulsivity developed by Evenden and colleagues. For further details of the methods, see text

Drug (pharmacological activity)	Unreliable visual discrimination (preparation)	Paced fixed consecutive number (execution)	Variable delay of rein forcement (outcome)
Ethanol	–	–	↑
Amphetamine	–	↑	↑
Haloperidol	↓	↑	–
Imipramine	↓	↓	–
Citalopram (SSRI)	–	–	–
8-OH-DPAT(5-HT_{1A} agonist)	↑↓	↓	X
DOI(5-HT_2 agonist)	↓	↑	↑
WAY-100635(5-HT_{1A} antagonist)	–	↑	–
Ritanserin(5-HT_2 antagonist)	↑	–	–

Key SSRI selective serotonin reuptake inhibitor)
↓ Reduction in impulsivity measures
– No effect on impulsivity measures
↑ Increase in impulsivity measures
X other effect

ed by Evenden (1998a, 1998b, 1998c, 1999a, 1999b) and Evenden and Ryan (1996, 1999). The picture given by these results is quite complex. However, one thing is evident; most of the drugs listed in the table did not have the same effect in all three tests. Some examples can be listed as follows:

– Ethanol increased the impulsivity score in the delay of reinforcement procedure, but had no effect in the unreliable visual discrimination or the paced FCN tests.
– Amphetamine dramatically increased the impulsivity score in the paced FCN test, produced a small increase in the impulsivity score in the delay of reinforcement procedure, but had no effect in the unreliable visual discrimination.
– The tricyclic antidepressant imipramine reduced the impulsivity score in both the paced FCN and unreliable visual discrimination, whereas the antipsychotic, haloperidol, actually increased the impulsivity score in the paced FCN, supporting the suggestion that tricyclic antidepressants might be more useful for controlling clinical impulsivity than antipsychotics. Interestingly the anti-impulsivity effect of impramine was not shared by the selective serotonin reuptake inhibitor, citalopram.
– Stimulation of 5-HT_2 receptors using the agonist, DOI, increased impulsivity scores in the paced FCN and delay of reinforcement procedures, but reduced impulsivity scores in the unreliable visual discrimination. In contrast, stimulation of 5-HT_{1A} receptors using the agonist 8-OH-DPAT reduced impulsivity scores in the paced FCN and the unreliable visual discrimination. These latter data suggest that the role of the serotonergic systems in controlling impulsivity may be more complex than previously envisaged, and that serotonin may influence different aspects of impulsivity in different ways depending upon the importance of the various receptor sub-types.

So far, the drug experiments strongly support the hypothesis that impulsivity is multifactorial, and that these factors have different biological bases. However, there are certain limitations in interpreting these results which must be respected. First, these experiments have been carried out in rats, and not man. Second, although attempts have been made to eliminate as many confounding factors as possible, there may still be ways in which impulsivity scores can be affected without there being a true change in impulsivity – some of the results in the delay of reinforcement procedure suggest this. For example, ethanol causes rats to respond on the lever associated with the small, immediate reinforcer even when the delay associated with the larger reinforcer is also zero. To account for such data it is necessary to appeal to the concept of an “average” delay associated with each lever, rather than the trial-specific delay. Certainly, a switch from a lever associated “on average” with delayed reinforcement to a lever never associated with delayed reinforcement can be interpreted as a form of impulsivity, but this is not an entirely satisfactory definition. Third, only one procedure has been used to measure each factor, so that specific factors relating to the particular procedure might influence the outcome of a drug study. Many ways of improving the procedures can easily be envisaged, and it is to be hoped that the future will provide opportunities to test these further.

The simple three-factor framework used to help with the design of these tests suffers from the same problems as many other schemas of its type. It does not fully explain all the data, and thus, like the hypotheses centred on delay of reinforcement or timing described above, it may be necessary to patch it up with a series of additional factors. I have identified two so far, which are of some conceptual importance.

The first of these concerns so-called “premature responses”, which can be defined as responses made before any information is available as to which response is appropriate, and which are inevitably wrong. The effects of various drugs in the uncertain visual discrimination indicate that there is a correlation between the likelihood of the rat pressing the lever prematurely, before the signal starts, and average reaction time once the stimulus has been turned on (i.e. few premature response, long reaction time) in many cases, but this is not always so. For example, amphetamine produced a dramatic increase in premature responses, but had no effect on reaction time. Somehow, the availability of information to steer the response choice seems to counteract the psychomotor stimulant effects of the drug. Evenden (1998c) advanced the hypothesis that premature responses on this procedure may be more related to “execution” than “preparation”, and that the act of withholding a response may be considered as a form of response chain where the behaviour consists of doing anything else except responding. However, the 5-HT_2 agonist DOI did not increase premature responding in the uncertain visual discrimination, although it did increase the impulsivity score in the paced FCN at the same doses. Thus the two behaviours are dissociable pharmacologically.

Premature responding is especially interesting in that this type of responding crops up as an error in many cognitive tests, and quite a lot of data about the neurobiological control of premature responses are available. For example, Sirviö and colleagues (Puumala et al. 1996; Puumala and Sirviö 1998) have studied the intercorrelations between different performance parameters in the five-choice serial reaction time procedure, originally developed as a procedure to measure attention (Carli et al 1983). They found that there was a significant negative correlation between the accuracy of performance and the number of premature responses. They have suggested that rats expressing this syndrome to an extreme degree may be an animal model of ADHD. In contrast to my findings in the uncertain visual discrimination (Evenden, unpublished data), this group have found evidence that premature responses in the five-choice test are sensitive

to manipulations of the 5-HT_2 receptor, being reduced by 5-HT_2 antagonists and increased by 5-HT_2 agonists (Ruotsalainen et al. 1997; Koskinen et al. 1998). A serotonergic involvement was also been demonstrated by Harrison et al. (1997), who examined the effects of 5,7-DHT lesions of the raphé nuclei on the same task. These lesions depleted central serotonin and produced a large and long-lasting increase in premature responses. Clearly, considerably more research is needed with this paradigm to reconcile these results. The neurobiology of response initiation has also been the subject of several more specific studies (e.g. Carli et al. 1985, 1989; Amalric et al. 1995; Baunez 1995, 1998; Ward and Brown 1995; Baunez and Amalric 1996; Brown et al. 1996). These studies are too complex to go into here, but are important in any discussion of the biological mechanisms influencing premature responding.

Persistence is another aspect of impulsivity which is not well-captured in the experiments described above. Persistence can be defined as the tendency to pursue goal-directed behaviour for a long time in unfavourable circumstances. In some sense this concept is captured by the progressive ratio schedule of reinforcement, nowadays frequently used in studies of the reinforcing mechanism of abused drugs (Markou et al. 1993). In this procedure, the number of responses required to obtain a reinforcer of a constant size is increased as the session continues, until eventually the subject stops responding (or pauses for longer than a pre-set criterion), thus providing a measure of persistence. However, this procedure has two weak points. First, it is based upon the rate of responding, and thus is susceptible to drug induced changes in the level of activation. Second, it fails to separate between persistent and perseverative behaviour, i.e. behavioural output which is not obviously goal-directed or which may even postpone achievement of the goal (also can be conceived as behavioural control by exteroceptive reinforcers or by interoceptive reinforcers, respectively). Perseverative behaviour is well illustrated by the study of Evenden and Robbins (1983) in which rats treated with amphetamine continued to switch between two response levers, in the presence of a signal indicating that they should open a centrally located panel to pick up the food reinforcer (i.e. they also showed perseverative switching). Amphetamine also increases the amount of responding under progressive ratio schedules, but it is unclear whether this is persistent or perseverative.

Conclusions

This article has reviewed a number of different approaches to the analysing impulsivity from the study of human personality traits, through psychiatric symptoms to animal behaviour. Although some authors have initially attempted to couple the whole or at least a large part of the behaviour generally classified as impulsive to one explanatory factor, they have ultimately had to concede that a satisfactory explanation demands several independent, interacting factors. Many authors have assumed that this is the case a priori. A list of the different suggestions quoted in this review as to what these factors might be, together with some attempt at a brief definition, can be found in Table 2 and Table 6. Even though almost all authors are in agreement that impulsivity is multifactorial, there is little agreement as to what these factors are even within a single field of research, such as human personality traits, let alone across fields. Some of this disagreement may come from the different theoretical approaches taken by the authors as a starting point. Behaviourists (such as Rachlin 1995) have often been

Table 6 Varieties of impulsivity proposed by various researchers working mainly with non-human subjects cited in the text with definitions or examples

Soubrié (1986)	Response inhibition	Serotonergic neurones are brought into play whenever behavioural inhibition is required
Logue (1988)	Resistance to delay of reinforcement	Impulsives cannot wait for delayed reward and have problems with delay of gratification
Bradshaw and colleagues	Timing	Impulsives show poor temporal judgements. Intervals reproduced too short
Ho et al. (1998)	Behavioural switching	Increased frequency of switching between response alternatives
Brunner and Hen (1997)	Motor impulsivity	Failure to inhibit behaviour, characterised by fast, inaccurate responding
	Cognitive impulsivity	Distorted judgement of alternative outcomes, resulting in a loss of reward in the long term
Evenden (1998d)	Preparation	Not all relevant information is taken into account before making a decision
	Execution	The behaviour chain is terminated before the goal is reached
	Outcome	A quick, but less valuable outcome is chosen rather than a later but more valuable
Evenden (see text) Possible additional factors	Premature responding	Responding when the opportunity is given before discriminating information available
	Lack of persistence	Quantitatively less behaviour emitted than normally expected

critical of definitions of impulsivity which rely on introspective, spiritual factors, such as "human will" (like those taken from the medical dictionaries cited at the start of this review). However, contrary to the impression sometimes given, a behaviourist approach does not necessitate a one-factor approach or a narrow application of particular mathematical equations.

As yet, there is no external method of checking, let alone validating the different proposals. One possibility by which this could be done is by appealing to neurobiology. Neurobiological techniques, including psychopharmacology, provide an additional set of tools for dissecting broadly defined psychological or behavioural concepts like impulsivity, and which may provide a reality-check against excesses of speculation and theory building. Unfortunately, these techniques have their own problems. For example, there are obvious limits in the way neurobiological techniques can be applied to human subjects, and sometimes neurobiological theories of psychological or psychiatric phenomena lack good support from experimental data. On the other hand, the progress of knowledge in neurobiology is driven by a different set of processes than that in behavioural sciences, and thus the possibility for synergistic progress remains.

Finally, consideration of impulsivity as the modulatory effect of several different factors on behaviour may provide better insight into the pathology than at present. The different aspects of impulsivity evident in different psychiatric (or neurological) syndromes may then be able to be placed in a more satisfactory explanatory framework. Hope for a single treatment against all forms of pathological impulsivity offered temptingly by the hypothesis that low serotonergic activity is responsible may be dashed, but given the fairly modest results of SSRI treatment this may not be disadvantageous. Instead more focused studies can be carried out which may help to identify treatments which may have a narrower profile of use, but better effect. Abandoning a monolithic view of impulsivity may make it easier to design and interpret studies on the genetic base of impulsivity which almost inevitably will point to polygenetic influences.

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References

Al-Zahrani SSA, Ho M-Y, Velazquez-Martinez DN, Lopez Cabrera M, Bradshaw CM, Szabadi E (1996) Effect of the destruction of the 5-hydroxytryptaminergic pathways on behavioural timing and "switching" in a free-operant psychophysical procedure. Psychopharmacology 127:346–352

Amalric M, Moukhles H, Nieoullon A, Daszuta A (1995) Complex deficits on reaction time performance following bilateral intrastriatal 6-OHDA infusion in the rat. Eur J Neurosci 7: 972–980

American Psychiatric Association (1994) Diagnostic and statistical manual of mental disorders, DSM-IV, 4th edn. American Psychiatric Association, Washington, D.C.

Anderson DM (ed) (1994) Dorland's Illustrated Medical Dictionary, 28th edn. Saunders, Philadelphia

Barratt ES (1983) The biological basis of impulsiveness: the significance of timing and rhythm disorders. Person Indiv Diff 4: 387–391

Barratt ES (1994) Impulsiveness and aggression. In: Monahan J, Steadman HJ (eds) Violence and mental disorder. University of Chicago Press, Chicago, pp 61–79

Barratt ES, Patton JH (1983) Impulsivity: cognitive, behavioural and psychophysiological correlates. In: Zuckerman M (ed) Biological bases of sensation seeking, impulsivity, and anxiety. Lawrence Erlbaum Associates, Hillsdale, New Jersey, pp 77–122

Baunez C, Amalric M (1996) Evidence for functional differences between entopeduncular nucleus and substantia nigra: effects of APV (DL-2-amino-5-phosphonovaleric acid) microinfusion on reaction time performance in the rat. Eur J Neurosci 8: 1972–1982

Baunez C, Nieoullon A, Amalric M (1995) In a rat model of parkinsonism, lesions of the subthalamic nucleus reverse increases of reaction time but induce a dramatic premature responding deficit. J Neurosci 15:6531–6541

Baunez C, Salin P, Nieoullon A, Amalric M (1998) Impaired performance in a conditioned reaction time task after thermocoagulatory lesions of the fronto-parietal cortex in rats. Cereb Cortex 8:301–309

Bizot J-C, Thiébot M-H, Le Bihan C, Soubrié P, Simon P (1988) Effects of imipramine-like drugs and serotonin uptake blockers on delay of reward in rats. Possible implication in the behavioral mechanism of action of antidepressants. J Pharmacol Exp Ther 246:1144–1151

Block J, Block JH, Harrington DM (1974) Some misgivings about the matching familiar figures test as a measure of reflection-impulsivity. Dev Psychol 10:611–632

Brown VJ, Brasted PJ, Bowman EM (1996) The effect of systemic *d*-amphetamine on motor versus motivational processes in the rat. Psychopharmacology 128:171–180

Brunner D, Hen R (1997) Insights into the neurobiology of impulsive behavior from serotonin receptor knockout mice. Ann NY Acad Sci 836:81–105

Buss AH, Plomin R (1975) A temperament theory of personality development. Wiley, New York

Carli M, Robbins TW, Evenden JL, Everitt BJ (1983) Effects of lesions to ascending noradrenergic neurones on performance of a 5-choice serial reaction task in rats: implications for theories of dorsal noradrenergic bundle function based on selective attention and arousal. Behav Brain Res 9: 361–380

Carli M, Evenden JL, Robbins TW (1985) Depletion of unilateral striatal dopamine impairs initiation of contralateral actions and not sensory attention. Nature 313:679–682

Carli M, Jones GH, Robbins TW (1989)Effects of unilateral dorsal and ventral striatal dopamine depletion on visual neglect in the rat: a neural and behavioural analysis. Neuroscience 29: 309–327

Carter CJ, Pycock CJ (1978) Differential effect of central serotonin manipulation on hyperactive and stereotyped behaviour. Life Sci 23:953–960

Cloninger CR (1987) A systematic method for clinical description and classification of personality variants. Arch Gen Psychiatry 44:573–588

Cloninger CR, Svrakic DM, Pryzbeck TR (1993) A psychobiological model of temperament and character. Arch Gen Psychiatry 50:975–990

Daruna JH, Barnes PA (1993) A neurodevelopmental view of impulsivity. In: McCown WG, Johnson JL, Shure MB (eds) The impulsive client: theory, research and treatment. American Psychological Association, Washington, D.C.

Dickman SJ (1985) Impulsivity and perception: individual differences in the processing of the local and global dimensions of stimuli. J Person Soc Psychol 48:133–149

Dickman SJ(1990) Functional and dysfunctional impulsivity: personality and cognitive correlates. J Person Soc Psychol 58: 95–102

Dickman SJ (1993) Impulsivity and information processing. In: McCown WG, Johnson JL, Shure MB (eds) The impulsive client: theory, research and treatment. American Psychological Association, Washington, D.C., pp 151–184

Evenden (1998a) The pharmacology of impulsive behaviour in rats II: the effects of amphetamine, haloperidol, imipramine, chlordiazepoxide and other drugs on fixed consecutive number schedules (FCN 8 and FCN 32). Psychopharmacology 138: 283–294

Evenden (1998b) The pharmacology of impulsive behaviour in rats III: the effects of amphetamine, haloperidol, imipramine, chlordiazepoxide and ethanol on a paced fixed consecutive number schedule. Psychopharmacology 138:295–304

Evenden JL (1998c) The pharmacology of impulsive behaviour in rats IV: the effects of selective serotonergic agents on a paced fixed consecutive number schedule. Psychopharmacology 140: 319–330

Evenden JL (1998d) Serotonergic and steroidal influences on impulsive behaviour in rats. Comp Summaries of Uppsala Dissertations from the Faculty of Medicine, p 764

Evenden JL (1999a) The pharmacology of impulsive behaviour in rats V: the effects of drugs on responding under a discrimination task using unreliable visual stimuli. Psychopharmacology, 143:111–122

Evenden JL (1999b) The pharmacology of impulsive behaviour in rats VII: the effects of serotonergic agonists and antagonists on responding under a discrimination task using unreliable visual stimuli. Psychopharmacology 146:422–431

Evenden JL, Robbins TW (1983) Increased response switching, perseveration and perseverative switching following *d*-amphetamine in the rat. Psychopharmacology 80:67–73

Evenden JL, Ryan CN (1996) The pharmacology of impulsive behaviour in rats: the effects of drugs on response choice with varying delays of reinforcement. Psychopharmacology 128:161–170

Evenden JL, Ryan CN (1999) The pharmacology of impulsive behaviour in rats VI: the effects of ethanol and selective serotonergic drugs on response choice with varying delays of reinforcement. Psychopharmacology 146:413–421

Evenden JL, Ryan CN, Mattila ME (1993) Behavioural testing of antidepressants: a practical preclinical approach to clinical problems. In: Sahgal A (ed) Behavioural neuroscience: a practical approach, vol II. Oxford University Press, Oxford

Eysenck HJ (1967) The biological basis of personality. Charles C. Thomas, Springfield, Ill.

Eysenck HJ (1993) The nature of impulsivity. In: McCown WG, Johnson JL, Shure MB (eds) The impulsive client: theory, research and treatment. American Psychological Association, Washington, D.C.

Eysenck HJ, Eysenck MW (1985) Personality and individual differences: a natural science approach. Plenum Press, New York

Eysenck SGB (1993) The I7: development of a measure of impulsivity and its relationship to the superfactors of personality. In: McCown WG, Johnson JL, Shure MB (eds) The impulsive client: theory, research and treatment. American Psychological Association, Washington, D.C.

Graham S, Ho M-Y, Bradshaw CM, Szabadi E (1994) Facilitated acquisition of a temporal discrimination following destruction of the ascending 5-hydroxytryptaminergic pathways. Psychopharmacology 116:373–378

Harrison AA, Everitt BJ, Robbins TW (1997) Central 5-HT depletion enhances impulsive responding without affecting the accuracy of attentional performance: interactions with dopaminergic mechanisms. Psychopharmacology 133:329–342

Herrnstein RJ (1970) On the law of effect. J Exp Anal Behav 13: 243–266

Ho M-Y, Al-Zahrani SSA, Velazquez-Martinez DN, Lopez Cabrerea M, Bradshaw CM, Szabadi E (1995) The role of the ascending 5-hydroytryptaminergic pathways in timing behaviour: further observations with the interval bisection task. Psychopharmacology 120:213–219

Ho M-Y, Al-Zahrani SSA, Al-Rumaitea ASA, Bradshaw CM, Szabadi E (1998) 5-Hydroxytryptamine and impulse control: prospects for a behavioural analysis. J Psychopharmacol 12:68–78

Kagan J (1966) Reflection-impulsivity: the generality and dynamics of conceptual tempo. J Abnorm Psychol 71:17–24

Koenigsberg R (ed) (1989) Churchill's Medical Dictionary. Churchill Livingstone, New York

Koskinen T, Ruotsalainen S, Puumala T, Lappalainen R, Koivisto E, Männistö PT, Sirviö J (1998) The role of 5-HT_{2A} receptors in the modulation of attention and response control in rats. Poster Presentation, 4th Iuphar Satellite Meeting on Serotonin, Rotterdam, July 23–25

Lecrubier Y, Braconnier A, Said S, Payan C (1995) The impulsivity rating scale (IRS): preliminary results. Eur Psychiatry 10: 331–338

Linnoila M, Virkkunen M, Scheinin M, Nuutila A, Rimon R, Goodwin FK (1983) Low cerebrospinal fluid 5-hydroxyindolacetic acid concentration differentiates impulsive from nonimpulsive violent behavior. Life Sci 33:2609–2614

Linnoila M, Virkkunen M, George T, Higley D (1993) Impulse control disorders. Int Clin Paychopharmacol 8:53–56

Logue AW (1988) Research on self-control: an integrated framework. Behav Brain Sci 11:665–709

Logue AW (1995) Self-control. Prentice-Hall, Englewood Cliffs, N.J.

Logue AW, Rodriguez ML. Pena-Correal TE, Mauro BC (1984) Choice in a self-control paradigm: quantification of experience based differences. J Exp Anal Behav 41:53–67

Markou A, Weiss F, Gold LH, Caine SB, Schulteis G, Koob GF (1993) Animal models of drug craving. Psychopharmacology 112:163–82

Mattila-Evenden M, Svanborg P, Gustavsson P, Åsberg M (1996) Determinants of self-rating and expert rating concordance in psychiatric out-patients, using the affective subscales of the CPRS. Acta Psychiatr Scand 94:386–396

Mazur JE, Logue AW (1978) Choice in a "self-control" paradigm: effects of a fading procedure. J Exp Anal Behav 30:11–17

Mehlman PT, Higley JD, Faucher I, Lilly AA, Taub DM, Vickers J, Suomi SJ, Linnoila M (1994) Low CSF 5-HIAA concentrations and severe aggression and impaired impulse control in nonhuman primates. Am J Psychiatry 151:1485–1491

Morrissey G, Wogar MA, Bradshaw CM, Szabadi E (1993) Effect of lesions of the ascending 5-hydroxytryptamine pathways on timing behaviour investigated with the interval bisection task. Psychopharmacology 112:80–85

Morrissey G, Ho M-Y, Wogar MA. Bradshaw CM, Szabadi E (1994) Effect of lesions of the ascending 5-hydroxytryptamine pathways on timing behaviour investigated with the fixed-interval peak procedure. Psychopharmacology 114:463–468

Newman JP (1987) Reaction to punishment in extravert and psychopaths: implications for the impulsive behaviour of disinhibited individuals. J Res Person 21:464–480

Newman JP, Widom CS, Nathan S (1985) Passive avoidance in syndromes of disinhibition: psychopathy and extraversion. J Person Soc Psychol 48:1316–1327

Patton JH, Stanford MS, Barratt ES (1995) Factor structure of the Barratt Impulsiveness Scale. J Clin Psychol 51:768–774

Puumala T, Sirviö J (1998) Changes in activities of dopamine and serotonin systems in the frontal cortex underlie poor choice accuracy and impulsivity of rats in an attention task. Neuroscience 83:489–499

Puumala T, Ruotsalainen S, Jäkälä P. Koivisto E, Riekkinen P Jr, Sirviö J (1996) Behavioral and pharmacological studies on the validation of a new animal model for attention deficit hyperactivity disorder. Neurobiol Learn Mem 66:198–211

Rachlin H (1995) Self control: beyond commitment. Behav Brain Sci 18:109–159

Rachlin H, Green L (1972) Commitment, choice and self-control. J Exp Anal Behav 17:15–22

Ruotsalainen S, Sirviö J, Jäkälä P, Puumala T, MacDonald E, Riekkinen P Sr (1997) Differential effects of three 5-HT receptor antagonists on the performance of rats in attentional

and working memory tasks. Eur Neuropsychopharmacol 7: 99–108
Schalling D, Asberg M, Edman G, Oreland L (1987) Markers for vulnerability to psychopathology: temperament traits associated with platelet MAO activity. Acta Psychiatr Scand 76: 172–182
Soubrié P (1986) Reconciling the role of central serotonin neurones in human and animal behaviour. Behav Brain Sci 9: 319–364
Spraycar M (ed) (1995) Stedman's Medical Dictionary, 26th edn. Williams & Wilkins, Baltimore
Srebro B, Lorens SA (1975) Behavioral effects of selective midbrain raphe lesions in the rat. Brain Res 89:303–325
Thiébot M-H, Le Bihan C, Soubrié P, Simon P (1985) Benzodiazepines reduce the tolerance to reward delay in rats. Psychopharmacology 86:147–153
van den Broek MD, Bradshw CM, Szabadi E (1987) Behaviour of "impulsive" and "non-impulsive" humans in a temporal differentiation schedule of reinforcement. Person Indiv Diff 8:33–239
van den Broek MD, Bradshaw CM, Szabadi E (1992) Performance of impulsive and non-impulsive subjects on two temporal differentiation tasks. Person Indiv Diff 13:169–174
Ward NM, Brown VJ (1997) Deficits in response initiation, but not attention, following excitotoxic lesions of posterior parietal cortex in the rat. Brain Res 775:81–90