The self-perceived survival ability and reproductive fitness (SPFit) theory of substance use disorders

David B. Newlin

National Institute on Drug Abuse—Intramural Research Program, Molecular Neurobiology Branch, Baltimore, MD, USA

Correspondence to:
David B. Newlin
NIDA—Intramural
5500 Nathan Shock Drive
Baltimore, MD 21224
USA
E-mail: dnewlin@intra.nida.nih.gov

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ABSTRACT

A new theory of substance use disorders is proposed—the SPFit theory—that is based on evolutionary biology and adaptive systems. Self-perceived survival ability and reproductive fitness (SPFit) is proposed as a human psychobiological construct that prioritizes and organizes (i.e. motivates) behavior, but is highly vulnerable to temporary, artificial activation by drugs of abuse. Autoshaping/sign-tracking/feature positive phenomena are proposed to underlie the development of craving and expectations about drugs as the individual learns that abused drugs will easily and reliably inflate SPFit. The cortico–mesolimbic dopamine system and its modulating interconnections are viewed as the biological substrate of SPFit; it is proposed to be a survival and reproductive motivation system rather than a reward center or reward pathway. Finally, the concept of modularity of mind is applied to the SPFit construct. Although considerable empirical data are consistent with the theory, new research is needed to test specific hypotheses derived from SPFit theory.

KEYWORDS Alcoholism, drug abuse, evolutionary biology, autoshaping, mesolimbic dopamine, modularity, motivation.

INTRODUCTION

Current evidence supports the conclusion that substance use disorders (SUD), including alcohol and other drug abuse and dependence, have complex, multi-factorial etiologies. Family (Cotton 1987), twin (Pickens *et al.* 1991; Prescott & Kendler 1999) and adoption studies (Goodwin *et al.* 1973) implicate genetic factors in the development of alcoholism although the precise genetic mechanisms are only now being identified (Long *et al.* 1998; Reich *et al.* 1998). There are also major environmental components to risk for SUD, such as peer influence, drug availability and environmental effects of parental alcoholism (e.g. Newlin *et al.* 2000). Theories of SUD are needed that integrate diverse etiological pathways in order to organize and synthesize the large body of data on the causes of SUD. Rigorous experimental tests are needed also for these new theories to fulfill their heuristic promise and to provide foundations that are empirically sound.

The purpose of this discussion is to propose a new theory of the etiology of SUD. This theory depends heavily on new concepts that, taken together, define an emerging model of SUD. These constructs include: (1) self-perceived survival ability and reproductive fitness (SPFit) (see also Newlin 1999); (2) the conclusion that the proposed brain substrate of SPFit, the cortico–mesolimbic dopamine (CMDA) system, is not a 'reward center' or 'reward pathway' as the addictions field has often assumed; instead, the CMDA is a basic survival and reproductive motivation system that is activated by both drugs of abuse and by perceived threats to survival and reproductive fitness (i.e. stressful and novel stimuli); (3) autoshaping/sign-tracking/feature positive (Hearst & Jenkins 1974) models of drug craving and of SPFit; and (4) modularity of mind (Fodor 1983). These concepts provide unifying systems for this new theory of SUD and suggest empirical tests that can falsify or uniquely support the theory.

The substance abuse field was originally dominated by the question, 'why do people take drugs that are clearly harmful to them and are addictive?' After the behavioral revolution and the rise of behavioral pharmacology, the question changed to 'why are abused drugs reinforcing to animals and to humans?' This is a much more limited and theoretically constrained question. In this paper, we return to the original question, cast in the framework of evolutionary biology.

SELF-PERCEIVED SURVIVAL ABILITY AND REPRODUCTIVE FITNESS (SPFIT)

Definition

The first concept is SPFit—a new psychological construct based on the fundamental mammalian motivations to enhance and to protect survival and reproductive fitness. In humans, SPFit represents an internalized, self-perceived model of survival and reproductive functioning. SPFit is embodied in such basic psychological characteristics as feelings of personal power, control, and omnipotence—related to survival ability, and to feelings of personal sexiness (i.e. that relevant others find them sexually attractive), physical and behavioral attractiveness and social desirability—related to reproductive fitness. SPFit organizes and prioritizes behavior in a complex world. Moreover, these evolutionarily conserved mechanisms are not viewed as limited to rare circumstances, such as the so-called 'fight or flight' response to direct threat, but are instead pervasive in human functioning and are tonically active.

As with intelligence quotient (IQ), SPFit is not designed or intended to account for or to measure racial and ethnic differences, and should not be used for this purpose. The SPFit construct would be construed and measured very differently if it were explicitly designed to perform this function.

Power motivation (McClelland 1974) is directly relevant to SPFit. Specifically, the desire to acquire and to enhance personal power is understood in the current theory as fundamental to the perceived ability to survive. The powerful person is better able to overcome obstacles to survival than the less powerful individual, and personal empowerment is thought to promote one's life relatively directly. Reproductive fitness is a fundamental concept in evolutionary biology, and can also be considered important in human behavior (without the assumption of exclusively genetic control). Humans go to extraordinary lengths to make themselves more physically, socially, and sexually attractive, and sexuality is integral to much human functioning. In terms of Darwinian natural selection, survival and reproductive functions are under the most intense selective pressure. Miller (2000) argued recently that in the evolution of mankind, natural selection for reproductive fitness may have played a greater role than did survival fitness. He suggested that 'runaway evolution' occurred for characteristics related to sexuality and reproductive fitness. For example, this selective pressure for sexual characteristics may have accounted for the development of the human 'big brain'.

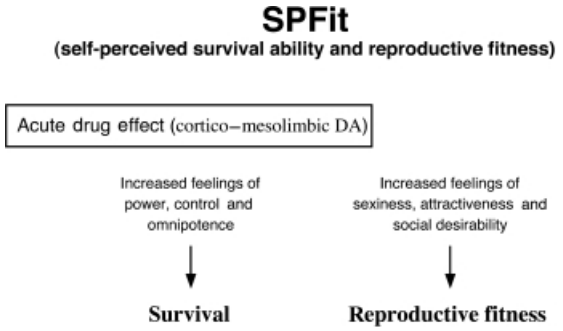

Figure 1 Schematic of SPFit. Note that SPFit does not employ 'reinforcement' or 'reward', or even 'euphoria' as explanatory constructs. The acute drug effect involves increased SPFit, activation of the cortico–mesolimbic dopamine circuitry (its proposed biological substrate), and enhanced feelings of power and sexual attractiveness. The acute drug effect is activating—a characteristic of motivation—in this case to survive and to be reproductively fit

SPFit is schematized in Fig. 1, which relates the psychological construct of SPFit to its proposed brain substrate, the CMDA system and to subjective states that reflect basic survival and reproductive functioning. Note in Fig. 1 that prevailing hedonistic concepts concerning the acute effects of drugs, such as 'euphoria' and 'pleasure' and mechanistic concepts such as 'reinforcement' and 'reward' do not enter into the definition or the heuristics of SPFit. The current theory is not a hedonistic theory. It is instead a teleological model based on goal-directed motivations and behaviors to survive and to be reproductively fit. In the hierarchy of motivations, survival and reproductive fitness are vastly more basic to the animal and to the human than is pleasure-seeking. A mammal that lacks motivation will die, but one that lacks pleasure will not. Pleasurable sensations or euphoria from drugs are considered incidental or epiphenomenal in the current theory. They can result from artificially increased SPFit, such as from taking an abused drug, rather than affecting it. At the same time, negative affective states such as fear, anxiety and anger are as likely to result from activation of SPFit as are pleasurable states.

Clearly, the entire body including the brain is sculpted by evolution to increase chances of survival and reproduction. However, it is equally clear that the body and most areas of the brain are not survival and reproductive motivational systems. Most theorists would assign some

functions of motivation (in one form or another) to limbic and particularly ventral striatal areas. The unique viewpoint of SPFit is that the CMDA is not a reward center, but is instead a survival and reproductive motivational system that is actively engaged by any biologically relevant stimulus, whether positive, novel, aversive or threatening. A reward center or pathway would only be activated by positive primary reinforcers, also called rewards.

In humans, SPFit bridges the gap between the biological imperatives to survive and to reproduce, on one hand, and behavioral and physiological adaptation to a complex world on the other hand. SPFit is proposed as an internalized representation of these biological primitives (to survive and to reproduce) based on self-perception of personal power and sexual attractiveness. SPFit is not proposed as a measure of actual biological fitness, which can be measured only in non-human animals (i.e. fecundity). It is influenced strongly by social and cultural factors that impinge on a person's self-perception.

Note that SPFit refers to human functioning; it is undefined in non-human animals (other than perhaps some of the great apes) because it can be measured or manipulated only in humans. Moreover, the self-perceived aspect of the SPFit construct refers to higher cognitive functions (both excitatory and inhibitory) that may relate more to the frontal cortical and anterior cingulate brain circuitry of the CMDA, and the motivational aspects refer more to ventral striatal functions. In humans, the CMDA system and its many interconnections reflects both the internal representation of SPFit and the midbrain substrates for survival and reproductive motivation, although it may be hazardous to deconstruct a tightly regulated and vitally important brain system.

SPFit is directly relevant to substance abuse because drugs of abuse artificially inflate feelings of personal power and sexual attractiveness. For example, abusers report that cocaine produces feelings of omnipotence and power (Sherer *et al*. 1989), as well as heightened feelings of sexual attractiveness. The 'coasting' and 'absolute contentment' of opiate 'high' may reflect artificial feelings of satisfaction that survival and reproductive fitness (SPFit) are assured. Other drugs of abuse produce similar feelings to a greater or lesser extent. Power motivation has been studied in relation to alcohol intoxication, and enhanced feelings of power and masculinity in men (McClelland 1974) and feminine characteristics (i.e. nurturance) in women (Wilsnack 1974) have been reported with alcohol 'high'.

The central paradox in the drug abuse field is the question of why people use drugs that are clearly harmful to them and, in fact, reduce their biological fitness. SPFit theory suggests that this temporary artificial inflation of SPFit, which can be dramatic (such as in drug 'rush' or 'high'; Sherer *et al*. 1989), taps into basic biological motives (power and sexuality) and the evolutionary mechanisms that control them. SPFit theory is a new theory that differs markedly from other theoretical models of the etiology of SUDs.

Heuristics of SPFit theory

Fitness

The fundamental heuristics of the current theory are summarized in Table 1. The idea that mammals behave as if abused drugs increase their survival ability and reproductive fitness was noted above. Nesse & Berridge (1997) proposed that 'drugs of abuse create a signal in the brain that indicates, falsely, the arrival of a huge fitness benefit' (p. 64). Although they were discussing non-human animals, this heuristic communicates the basic motivational assumptions of SPFit theory as well as the role drugs of abuse may play in the life of a human. The idea is that abused drugs tap into a basic dimension of functioning that evolved for survival and reproduction in environments without such substances. Therefore, the current theory assumes that availability of such drugs is recent in evolutionary terms and that natural selection for substance abuse was not an important factor in human or mammalian evolution (however, see also Dudley 2000, 2002). Instead, drugs that are abused share the common characteristic of providing false information that the animal is increasing its survival and reproductive fitness by self-administering these substances. The human is boosting his/her SPFit by experimental, escalating and chronic abuse of such drugs, as well as relapse after cessation of drug use. Moreover, the false information to the brain is transient and artificial. For example, the intoxicated drinker may believe that he or she is behaving in an appealing manner (i.e. increased SPFit) when, in fact, they are making fools of themselves.

Nesse & Berridge's (1997) 'huge fitness benefit' is not synonymous with 'pleasure'. In fact, their theory emphasizes that drug liking' (reward) decreases with chronic use at the same time that 'drug wanting' (craving) increases (Robinson & Berridge 1993). Therefore, it would be erroneous to suggest that abused drugs are 'reinforcing' or 'rewarding' (to use terms from behavioral pharmacology) because they carry false information about fitness or because they increase SPFit. Instead, drugs are abused because they directly activate brain motivational systems that normally control survival and reproductive fitness, and in humans, because they increase SPFit. Hedonics are incidental, or a result-as opposed to a cause-of increased SPFit.

Table 1 Major components of SPFit theory.

(1) SPFit is a new psychobiological construct in humans that mediates between: (i) the primary motivation to survive and the secondary motivation to reproduce, and (ii) behavioral interactions with the social environment and the internal world of abused drugs. SPFit refers to self-perceived survival and reproductive fitness, not to actual fitness. This system is very flexible and adaptive, in part because it is internalized and self-reflective rather than hard-wired and invariant.
(2) A survival and reproductive motivation system is defined as one that: (i) is highly goal-directed (to survive and be reproductively fit), (ii) integrates sensory and other information and affect to further its goals, (iii) actively prioritizes and organizes behavior for the same purpose, (iv) responds to both positive and aversive or threatening stimuli, and (v) is characterized by relentless striving toward survival and reproductive fitness. In contrast, a reward center simply increases the likelihood of immediately preceding behavior when primary reinforcers are administered.
(3) The biological substrate of SPFit is the cortico–mesolimbic dopamine system and its neurophysiological connections. The self-reflective nature of SPFit is determined more by its cortical projections, and the motivational aspect by its ventral striatal components. It is not a reward center or reward pathway and, for example, it is very sensitive to novel and stressful stimuli that are not rewarding.
(4) Autoshaping/sign-tracking/feature positive. The learning mechanism by which these processes occur is autoshaping/sign-tracking. This involves self-sustaining behavioral and physiological processes by which the organism becomes oriented toward, attended to, and fixated on arbitrary stimuli that are highly predictive of activating biological events such as drug effects. The biological substrate of SPFit becomes sensitized during this process.
(5) Fixation/completion. The process of fixation/completion of the motivational system during and after puberty by the abuse of drugs is in part a learning process that supplants the more typical fixation/completion of this motivational system by culturally accepted functions such as mating rituals, schooling and gainful employment.
(6) Abused drugs 'hijack' the motivational system that evolved to regulate survival and reproductive functions. This process occurs because drugs activate this system as if they promoted survival and reproduction when they actually do not. Stressful stimuli also activate this motivational system because they are biologically relevant, although these stimuli do not produce feelings of reward, nor are they positively reinforcing.
(7) SPFit is likened to a vertical module of mind/brain (Fodor 1983) that controls survival and reproductive motivation. The 'impermeability' of a vertical module may explain the persistence of drug abuse and addiction, as well as the very high relapse rates associated with this disorder.

Table 2 Common factors that characterize the acute effects of highly diverse drugs of abuse.

Modality	*Common factor*	*Direction*
Behavioral	Self-administration	↑
	Pavlovian conditioning	↑
	Conditioned place preference	↑
	Locomotor activation	↑
	Autoshaping/sign-tracking	↑
Physiological	Dopamine efflux (n. accumbens)	↑
	EEG alpha (10 Hz)	↑
	P300 amplitude (event-related potential)	↓
	Global brain glucose utilization (PET)	↓
	Tachycardia	↑
	Vagal tone	↓
Subjective	Euphoria or 'high'	↑
	Craving	↑
	Cognitive expectancies	↑
Psychobiological	SPFit	↑

Although Nesse & Berridge's (1997) ideas concerning evolutionary approaches to substance abuse were seminal, they were not elaborated in terms of animal or human research and were not stated in ways that were testable (i.e. falsifiable). SPFit theory addresses these issues and represents a more articulated theoretical statement.

Common factors

An important heuristic of SPFit theory is that characteristics that are common to many abused drugs with vastly different pharmacological properties are important to understanding the psychobiological mechanisms of their abuse liability (Table 2). The idea that these common factors may all relate more or less directly to survival motivation and reproductive fitness is not current orthodoxy in the substance abuse field. This commonality is normally attributed to the central importance of the CMDA in the psychopharmacology of abused drugs, which SPFit theory views as the survival and reproductive motivation system.

Table 2 lists some of the common factors that have been identified in empirical research over the last few decades. The current theory predicts that new data using measures of SPFit (see below) will provide evidence that temporary elevation of SPFit is common to abused drugs but not to drugs that are subjectively neutral or aversive. This prediction is central to empirical tests of the current theory.

Genetics and environment

It is inherent in the definition of SPFit that it has both genetic and environmental components, and may represent genetic-environmental interaction. That is, the universal (in humans) *capacity* and *propensity* to develop SPFit and the underlying motivations to survive and to be reproductively fit are proposed to be under strong genetic control. Moreover, genetic factors may determine individual differences in the degree to which drugs of abuse artificially inflate this system. However, the specific *development* and *expression* of SPFit can be highly idiosyncratic and under strong environmental–cultural control. For example, all adult humans who are neurologically intact may be characterized in terms of their SPFit in general and in specific situations. However, bank presidents may define their own senses of power, control, sexual attractiveness, and social desirability (i.e. their SPFit) in terms of the number of people employed under them or the amount of their paychecks. Therefore the current theory is unrelated to the field of sociobiology, despite the fact that it employs certain theoretical notions from evolutionary psychology and animal behavior.

A good example of the difference between sociobiology and SPFit theory is Thornhill & Palmer's (1999) recent Darwinian analysis of rape. They argued that the function of heterosexual rape is not power and domination, but is instead a reproductive strategy to transmit the rapist's genes in the gene pool. In contrast, SPFit theory interprets rape as a deviant means to increase the rapist's SPFit, or the temporary enhancement of self-perceived power and reproductive fitness, rather than actual reproduction. Therefore, rape is viewed instead as a violent, dominating, humiliating, but also sexual, act. Actual reproduction may be merely incidental to the rapist. This SPFit interpretation applies equally to homosexual rape, which Thornhill & Palmer's (1999) analysis does not.

Natural selection

The development and expression of SPFit is viewed in this theory as controlled by natural selection involving characteristics that are determined by both Mendelian genetics and Lamarckian socio-cultural evolution. The term 'Lamarckian' is used advisedly here (despite its discredited connotations) to indicate that acquired psychosocial characteristics can be passed through generations by processes that are non-genetic, but that also depend on natural selection (C.R. Newlin, pers. comm.). This allows for very rapid cultural evolution because characteristics acquired in the life-times of the parents can be transferred directly to the offspring—i.e. meeting the definition of Lamarckian evolution. In fact, socio-cultural evolution through Larmarckian mechanisms reflects 'runaway' evolution in which change is extremely rapid, such as cultural change in the 20th century. The unifying principle is natural selection in both Mendelian and Lamarckian evolution.

EVIDENCE RELATING TO SPFIT

Power motivation

Power imagery

McClelland (1974) performed a series of studies in the 1960s concerning power motivation or the desire to maintain and increase one's power over self and others. He proposed that individuals drink alcohol to artificially enhance feelings of power. They measured power motivation using written fantasy material expressed by male volunteers who were administered the thematic apperception test (TAT), a standard projective test. Subjects took the TAT during various cocktail parties and discussion groups when alcohol was served compared with similar functions when alcohol was absent. TATs were administered before drinking and then twice after drinking, first at a moderate dose and then at a high dose of alcohol. Wilsnack (1974), a colleague of McClelland, summarized her mentor's research on alcohol as follows:

> 'Small to moderate amounts of alcohol were found to increase thoughts of social power (s Power), power for the good of others or a cause. Larger amounts of alcohol increased thoughts of personal power (p Power), power in the interest of self-aggrandizement, without regard for others. In two studies of working class men, men with histories of heavy drinking had higher p Power scores when not drinking than men with histories of light drinking' (p. 43).

Gender differences

Wilsnack (1974) found that women's TAT fantasies after consuming alcohol were unlike those of the men in the earlier studies. Among female drinkers, personal power (p Power) actually decreased after drinking relative to the condition without alcohol. Moreover, 'being orientation', a psychological measure that had in previous studies characterized nurturant women, increased markedly after alcohol. Although it is likely that women showed greater traditionally feminine characteristics after drinking, Wilsnack (1974) observed that the effect might represent only a decrease in masculine fantasy. In either case, there was strong evidence of gender differences in the response to alcohol in relation to power motivation.

Self-confidence

Although power motivation is fundamental to the SPFit concept, it is not a contemporary measure. Konovsky & Wilsnack (1982) measured self-confidence using the Tennessee self-concept scale administered at cocktail parties with married couples. Again, gender differences were striking; men scored higher in self-confidence after drinking, but women scored lower after alcohol.

Measurement

In order to test a new theory it is often necessary to develop new measures of constructs that are hypothesized to behave in specific ways. 'Articulated thoughts about simulated situations' (ATSS, Davison, Vodel & Coffman 1997) provides an appropriate laboratory procedure for measuring SPFit (M. Earleywine, pers. comm.). In this measurement system, the subject listens individually to an audiotape designed to produce emotional responses in the listener. An example is a tape in which the actor overhears peers being highly critical of him/her. As the tape is played to the subject, there are long silent pauses in which the subject is instructed to speak aloud his/her thoughts as if they were in the situation of the actor on the audiotape. ATSS, with intense time pressure put on the subject, tends to minimize self-editing of verbal content and allows more genuine emotional responses to the simulated situation. The spoken comments describing the subject's response to the situation on the tape are themselves audio- and video-taped so they can be assessed off-line.

Groups of judges are trained to rate the dependent variables of interest: expressed power, control and omnipotence and feelings related to sexiness, personal attractiveness and social desirability. The judges' ratings of SPFit, assuming adequate reliability, are correlated with vocal characteristics of the subject's spoken comments (such as voice volume and vocal stress analysis) and verbal content. Physiological measures such as heart rate, myocardial contractility, finger temperature and general locomotor activity are also recorded while subjects perform the ATSS task. Vocal and physiological responses occurring at points in time when trained judges rate SPFit to be unusually high or low for an individual subject are of particular interest.

A second component of SPFit is the 'perceived sphere of influence'. This construct represents the individual's internal representation of their assumed influence (power) on significant others in their social environment. This is measured by having the subject make a list of their significant others (family members, friends, sexual partners, employees or employers, etc.), and rating each one on the degree to which they influence these individuals and are influenced by them.

A related construct is the 'perceived dominance hierarchy'. The location in the dominance hierarchy that the individuals place themselves in various social systems (family, work, friends, etc.) is another measure of their perceived sphere of influence. This is a third component of measuring SPFit, with perceived position in the hierarchy as the dependent measure.

SPFit theory predicts that the intoxicated subject will show increased emotional responses and subjective (self-report) and physiological changes consistent with increased SPFit, compared to a sober state or to responses under placebo. If SPFit is elevated, subjects should view themselves as having an enlarged perceived sphere of influence and higher location in their perceived dominance hierarchy due to enhanced feelings of power, control and sexual desirability. Therefore, reliable and valid assessment of SPFit represents a challenging but solvable problem in empirical tests of the theory.

Self-efficacy and euphoria

Self-efficacy (Bandura 1977) is a psychological construct that has some overlap with SPFit. Self-efficacy is usually defined as a relatively specific belief that one can deal effectively with a specific stimulus or situation (contextual stimulus). It is a much less global construct than 'self-confidence' or 'self-esteem.' Bandura (1977) stated that: 'psychological procedures, whatever their form, serve as means of creating and strengthening expectations of personal efficacy' (p. 193). Therefore, self-efficacy is a cognitive theory that concerns expectancies about personal behavior and its outcomes. SPFit has some similarity in that it is based on self-perception, but it differs in that it emphasizes survival and reproductive fitness rather than specific stimuli such as a snake (self-efficacy) or life in general (self-confidence). Much of daily behavior is irrelevant or only indirectly relevant to survival and reproduction. Most of the time SPFit would not be so actively engaged as when, for example, someone were held under water or were ridiculed by peers. Moreover, SPFit might be very prominent in situations in which self-efficacy was low, such as when there was a direct threat to SPFit with which the individual felt poorly able to cope. Therefore, it is essential in the ATSS assessment procedure that self-efficacy is measured concurrently so that it can be covaried with SPFit. Of particular importance to the theory is variation in SPFit that cannot be predicted by self-efficacy beliefs in the expected success of a specific behavior in a specific situation. This residual might then be lawfully related to pharmacological manipulations (increased SPFit) and to organismic state,

such as decreased SPFit during drug withdrawal or influenza infection.

Researchers often measure pleasurable affective states ('euphoria', 'high', 'coasting', etc.) during intoxication from drugs such as cocaine, heroin, marijuana, and alcohol, as surrogate measures of drug 'reward' or 'reinforcement'. This follows from prevailing hedonistic models of SUD, whether behavioral or psychobiological. In contrast, heightened SPFit should be associated with both positive (e.g. omnipotence) and negative emotional states (e.g. stress responses). This sensitivity to negative emotional states is characteristic of SPFit, but not of hedonistic mechanisms such as 'reward' and 'reinforcement'. A corollary of this is that abused drugs administered acutely would be expected in SPFit theory to produce a wide range of positive and negative affective states, not just 'euphoria' or 'reward'. Again, the variation in SPFit that cannot be accounted for by changes in positive affect is particularly important in testing the theory.

Increased SPFit

The most important prediction of the model is that intoxication from alcohol and other abused drugs will inflate SPFit. Also, the perceived sphere of influence and the location in the perceived dominance hierarchy should increase during intoxication relative to a sober state. During the acute drug effect SPFit is artificially elevated at the same time that actual fitness may be seriously compromised by the drug. This potential discrepancy between self-perception and reality illustrates the fundamental nature of SPFit. The construct serves as a flexible buffer between the individual's ecology (e.g. survival and social demands) and his/her behavioral and physiological adaptation to that environment (coping with those demands). SPFit allows for clearly maladaptive behavior precisely because of the enhanced flexibility and greater adaptive capacity of an internalized system

Drug withdrawal

A corollary of the prediction that drugs of abuse will artificially boost SPFit is that states of drug withdrawal will be associated with SPFit that is depressed below baseline levels. Since SPFit is viewed as pervasive and paramount in human functioning, it is tonically active and can decrease at any time. In addition to measuring SPFit during withdrawal from drugs of abuse, one might also assess it in individuals who have influenza, those who have just learned they have a major disease, or individuals who are experiencing divorce or bereavement.

Biphasic responses

The effect of alcohol (and some other drugs) on SPFit may be biphasic, such that SPFit increases in the rising blood alcohol curve followed by decreased SPFit (below baseline levels) in the falling curve (Newlin & Thomson 1990). Brain responses to alcohol differ in the rising and falling blood alcohol limbs (Lyons, Whitlow & Porrino 1998). This effect can be biphasic in terms of dosage as well (Pohorecky 1977). Low doses of alcohol and other abused drugs that produce behavioral activation (locomotor and psychostimulant activation) in animals should be associated with temporary enhancement of SPFit in humans. In contrast, very high doses that de-activate behavior should depress SPFit acutely.

Stress

Hobfoll (1989) proposed a conceptual model of stress based on conservation of resources. He proposed that 'people strive to retain, protect and build resources and that what is threatening to them is the potential or actual loss of these valued resources (p. 513)'. If one simply replaces the word 'resources' with 'SPFit', the result is a new definition of stress that is integral to the current theory. When people are exposed to stressful stimuli (i.e. those that threaten SPFit), they seek to boost or to maintain SPFit in the face of potential losses. Therefore, both abused drugs and stressful stimuli can lead to temporarily elevated SPFit despite opposing affective valences of these two types of stimuli. It should be noted that prolonged, uncontrollable stressors can lead to sharply depressed SPFit if the person is unable to cope with these stimuli.

'Saving face' represents a similar phenomenon that is important in folk psychology and cultural anthropology. 'Saving face' in SPFit theory is the successful protection of SPFit in socially difficult situations, and 'losing face' represents decreased SPFit.

An important aspect of SPFit is that both positive and threatening stimuli tend to be activating. Psychologically, this activation reflects the mobilization of resources to survive or to be reproductively fit. Physiologically it is associated with engagement of the CMDA system, and behaviorally with directed locomotor activation (Wise & Bozarth 1987).

Risk-taking behavior

SPFit theory predicts increased risk-taking behavior in individuals under the influence of abused drugs because the enhanced sense of empowerment (survival ability) would tend to diminish their expectancy for adverse

outcomes from risky behavior (M. Fillmore, pers. comm.). For example, driving while intoxicated may be associated with enhanced SPFit and feelings of invulnerability. It is worth noting that drug-taking is itself risky behavior, whose perception of risk would also be diminished by the temporary boost in SPFit. This could lead to rapid, repeated dosing and to very high blood levels of the drug that are strongly associated with serious adverse consequences. This is also a potential mechanism of 'loss of control' drug use.

Summary

SPFit is new to psychology and biology. It captures and clarifies many characteristics of the acute response to alcohol and to other drugs, which provides a basis for its heuristic value. However it requires substantiation using sophisticated measurement techniques such as ATSS (Davison *et al*. 1997). The current theory makes strong, directional predictions concerning the empirical effects of acute intoxication and drug withdrawal on SPFit. It must also be demonstrated that SPFit is not merely redundant with self-efficacy or euphoric mood states. Therefore, SPFit meets the critical criterion of falsifiability.

AUTOSHAPING

Substance abuse involves acquired motivation. SPFit theory views autoshaping as a particularly important learning process in the etiology of substance abuse. Newlin (1992, 1999) argued that autoshaping may provide a conceptual and empirical link between drug conditioning and craving in both animals and humans. Autoshaping (Brown & Jenkins 1968), also called sign-tracking (Hearst & Jenkins 1974), is a procedure in which there is a Pavlovian contingency between an arbitrary stimulus (e.g. a light or presence of a manipulandum or lever) and presentation of a biologically relevant stimulus (e.g. food or a predator). The arbitrary stimulus acts as a conditioned stimulus that always directly precedes the unconditioned stimulus or signals (cues) that the unconditioned stimulus is imminent. This paradigm is Pavlovian because there is no contingency between the stimuli and the animal's behavior. The conditioned stimulus will precede the unconditioned stimulus no matter what, if anything, the animal does.

This phenomenon is also called sign-tracking because the animal (Hearst & Jenkins 1974) or human (Newman *et al*. 1980) shows directed movements (or tracking) toward the conditioned stimulus (or sign) that is highly predictive of a positive reinforcer. The conceptual similarity to craving is that in the addict, attention and behavior are directed toward stimuli, such as drug paraphernalia or drinking 'buddies', that have been strongly associated with or predictive of drug-taking behavior (Newlin 1992). Researchers are only now beginning to study autoshaping with drugs as unconditioned stimuli (Carroll & Lac 1993, 1997, 1998; Krank 1992).

Experimental findings from the 1960s demonstrated that, to the surprise of the investigators, the animal in this situation approaches and makes physical contact with the conditioned stimulus as if it were the unconditioned stimulus. For example, pigeons trained in an autoshaping procedure with a key light as the conditioned stimulus and food as the unconditioned stimulus will peck the key light when it is turned on; this occurs despite the fact that there is no contingency with the animal's behavior, so that it appears to be 'useless' behavior. In contrast, if the unconditioned stimulus is aversive, such as an electric shock, then the animal will direct its behavior away from the conditioned stimulus rather than toward it. The power of autoshaping/sign-tracking is that it is highly resistant to extinction, and the animal will persistently show directed movements toward the sign even if such movements prevent it from consuming the reinforcer. The latter effect indicates that autoshaping is more powerful, at least in this situation, than the 'law of effect' or instrumental conditioning.

Therefore, auto-shaping/sign-tracking appears to be a basic adaptive mechanism by which animals learn to orient toward and fixate on biologically relevant stimuli (or to avoid aversive stimuli). Bolles's (1972) incentive motivation theory, which has been very influential in the drug abuse field, emphasized the adaptive nature of incentive motivation, and the development of cognitive expectancies (see below) concerning biologically relevant stimuli:

> 'In both cases [auto-shaping and avoidance learning], the chief effect of putting the animal in the experimental situation is to produce an expectancy; an expectancy of food in the one instance [auto-shaping] and an expectancy of shock in the other [avoidance learning]. The animal then gives us its characteristic behavior; food-getting responses or defensive reactions' (p. 399).

It is important to note that autoshaping/sign-tracking is directed behavior toward the arbitrary sign of an unconditioned stimulus. It is not undirected locomotor activation, such as in response to low doses of abused drugs (Wise & Bozarth 1987), although this low-dose locomotor activation might be highly directed if there were a conditioned stimulus (or in fact, any stimulus) present in the cage.

Autoshaping/sign-tracking phenomena are not limited to autoshaping experiments. Any time that a stimulus is a reliable predictor of a biologically relevant

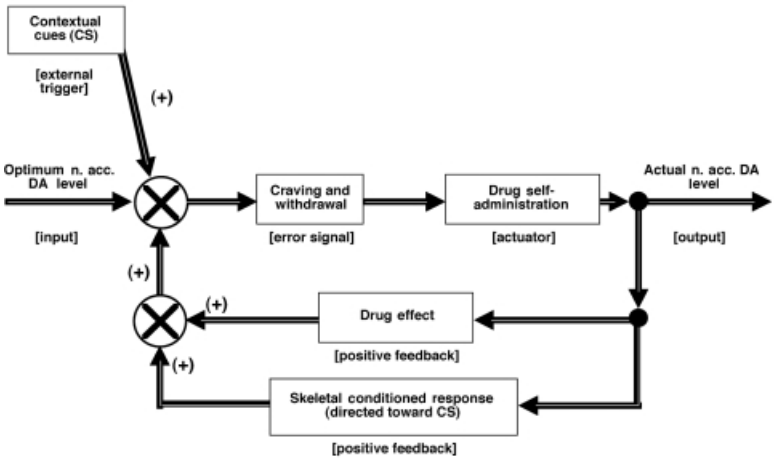

Figure 2 Formal control theory schematic diagram of the auto-shaping/sign-tracking/feature positive theory of drug craving and addiction. The organism 'seeks' an optimum DA level in the nucleus accumbens that is non-zero, which is the input to the system; the output is the actual DA level. Note that the control theory schematic incorporates brain neurochemical characteristics, subjective, behavioral and pharmacological factors into one functional system. The schematic is of a positive feedback system, which is inherently explosive (see text)

stimulus (such as a drug), the opportunity for the animal or human to sign-track the cue is present and is very likely to occur. The stimulus can be a discriminative stimulus signaling drug availability, an internal stimulus (such as a stress response or anxiety), a temporal stimulus (drinking alcohol before dinner), or a wide variety of other types of stimuli that are predictive of drug delivery. In the original conditioned place preference study with abused drugs, Mucha *et al*. (1982) pointed out that this procedure is a form of autoshaping, albeit a particularly cumbersome, awkward, labor-intensive form.

The autoshaping model of SUD is schematized in a formal control theory (Luenberger 1979) diagram in Fig. 2. This is a positive feedback model rather than negative feedback, which is the more usual case. Positive feedback systems are inherently explosive because there is no negative feedback to limit the system. For example, sexual intercourse can be modeled by a positive feedback system in which sexual arousal begets sexual behavior and sexual behavior begets sexual arousal; the limiting factor is orgasm. Therefore, this positive feedback system predicts bouts of intense drug-taking behavior, with some periods of no drug use. In this sense, it models the 'loss of control' over drug use phenomenon in SUD.

Autoshaping/sign-tracking is important for SPFit theory because it: (1) like SUD, is highly resistant to extinction, (2) produces very endurable priming or cuing effects of the sign of impending drug delivery, (3) integrates visceral (Pavlovian), skeletal (instrumental) and cognitive (expectancies) processes in one procedure, (4) suggests empirical tests of the theory and (5) provides a powerful model of acquired motivation.

Homeostatic models of addiction go back to Himmelsbach (1943), who proposed a negative feedback model of opiate dependence that is similar to Koob & Nestler's (1997) allosteric model. The primary differences are that Himmelsbach assumed that the set-point (system input in control theory terms) was related to hypothalamic function, while Koob argued that it is ventral striatal. Another difference is that Himmelsbach's model had a primary emphasis on aversive withdrawal states, while Koob's allosteric model emphasizes both reward and withdrawal. For example, Koob (2000) noted that drug self-administration studies 'prove the obvious: people use drugs based on a pleasurable activation of the brain's reward system (p. 543)', and 'a subject suffering from drug addiction may attempt to maintain an apparent stability of its reward function at a new pathological "set point"' (p. 545). This also illustrates the difference between Koob's model and the current theory; the former is a hedonic model while SPFit theory is a goal-oriented survival motivation model. Also, Koob's allosteric model is a negative feedback system (as was Himmelsbach's model), while Fig. 2 is a positive feedback system. A negative feedback system seeks homeostasis, while a positive feedback system is self-sustaining toward a continually higher state.

SPFit theory proposes that the common factors in psychopharmacology (Table 2) might be understood in terms of a super-ordinate factor of directed approach behavior, such as drug-seeking behavior. The observation (Salamone 1994) that microinjections of abused drugs in the mesolimbic area elicit biologically relevant approach behavior, such as sexual behavior and foraging, seems consistent with this view. Moreover, there is evidence (Parkinson *et al*. 2000) of involvement of the core of the nucleus accumbens (CMDA) in autoshaping behavior, also referred to as 'Pavlovian approach behavior.' This represents an important link among autoshaping, the CMDA, and the fundamental dimension of approach.

Empirical tests would involve (among many experiments) autoshaping studies in which both natural reinforcers and naturally aversive stimuli were employed as unconditioned stimuli, in addition to drugs. It would then be possible to record dopamine efflux in the nucleus accumbens as animals approached positive signs and

moved away from negative signs. Microdialysis techniques use sampling intervals that may be too slow to separate the conditioned from the unconditioned response (Shippenberg, He & Chefer 1999). However, voltametric techniques are sufficiently fast that they would allow this differentiation.

Drug craving

Newlin's (1992) auto-shaping/sign-tracking model of drug craving emphasized the very persistent orientation toward and skeletal behavior directed to drugs and to cues for drugs in drug abusers and addicts. This model of drug craving was integrated (Newlin 1999) into SPFit theory as a remarkable orientation of the substance abuser toward stimuli associated with drugs and to drugs, themselves, as means to artificially enhance SPFit.

Approach versus avoidance

Approach versus avoidance is a fundamental dimension of mammalian responses to environmental stimuli. For example, when presented with another animal or human, the organism immediately categorizes it as 'friend or foe, predator or prey?' or if it is a novel environment, as 'opportunity or threat?' Davidson (1992; Davidson & Irwin 1999) summarized electrophysiological data indicating that approach is associated with left frontal electroencephalographic activation, and avoidance with right frontal activation. This frontal asymmetry appears not to reflect the dimension of positive versus negative affect because anger, a negative emotion, also activates left frontal areas (Harmon-Jones & Allen 1998). Therefore, the approach versus avoidance dimension is more fundamental than is affective tone. Moreover, this frontal asymmetry has been a highly reliable empirical finding in the psychophysiology literature.

SPFit theory predicts that drugs of abuse and drug stimuli, such as paraphernalia, drinking buddies, advertisements for tobacco products and situations frequently associated with drug use, will produce left frontal brain activation and approach functioning only in drug abusers. Moreover, this approach dimension reflects sign-tracking, or orientation toward stimuli associated with drug effects and signals of impending drug availability and drug delivery. It also reflects the 'feature positive effect' (Newman *et al.* 1980) that is conceptually related to sign-tracking, or an over-emphasis on features that are positively rather than negatively related to or correlated with biologically relevant stimuli such as drugs.

Zinser et al. (1999) measured right and left frontal alpha power of the electroencephalogram in smokers deprived of cigarettes for 24 hours and after exposure to smoking cues and during actual smoking. Both deprivation and anticipation of smoking were associated with increased left frontal activation, and actual smoking reduced frontal brain asymmetry. Of different models of craving and addiction that were considered, the results were most consistent with Robinson & Berridge's (1993) incentive-sensitization model because the frontal brain response indicative of approach functioning occurred to anticipation and to exposure to smoking cues rather than to actual smoking.

In SPFit theory drug stimuli are viewed as cues for the opportunity to inflate SPFit. The current theory would predict that addicted individuals will show a short-term elevation in SPFit in response to such a cue, but only if the drug is available to them. If the drug is unavailable, there could be a transient decrease in SPFit. It is interesting to note that Tomie *et al.* (1998) have argued that autoshaping represents impulsive behavior. Drug craving is viewed in SPFit theory as impulsive responding. This contrasts markedly with Tiffany's (1990) proposal that drug craving represents controlled (effortful, deliberate and non-automatic) rather than automatic cognitive processes and with Cox & Klinger's (1988) description of craving as a cognitive decision-making process.

Cognitive bias

There is evidence (Earleywine 1994; Weingardt Stacy & Leigh 1996) that heavy users of alcohol have a cognitive bias toward alcohol-related stimuli. For example, Earleywine found that the tendency to understand words with double meanings, one of which is alcohol related (e.g. 'bar'), in terms of the alcohol-related meaning, was greater in individuals who drank the most alcohol. SPFit theory would interpret these results as due to sign-tracking of stimuli associated with alcohol.

It has been noted (K. Sher, pers. comm.) that the chronic smoker or drug abuser 'always has something to look forward to'—i.e. their next cigarette or injection of cocaine. They are always looking forward to or anticipating boosting SPFit, and this expectation is an important component of drug craving. Moreover, when they are attempting to quit using the drug they feel they 'have nothing to look forward to'. These considerations emphasize the degree to which drugs capture and control SPFit through the development of expectancies and craving.

Drug outcome expectancies

There is now a large human literature (Leigh 1989; Goldman *et al.* 1991) concerning beliefs and attitudes toward drugs (many of them false beliefs), which are particularly strong and positive among those who abuse and become dependent upon drugs. These attitudes and

beliefs are thought to play an important causal role in the development of drug abuse and addiction.

SPFit theory posits that autoshaping/sign-tracking/feature positive is a basic mechanism by which these positive beliefs and attitudes toward drugs develop during early use and abuse of these substances. Specifically, the drug user is learning that taking these drugs is an easy, highly reliable way to inflate SPFit, although they may be unaware that the inflation of SPFit is 'false' in the sense that the feelings do not correspond with reality. Moreover, drug outcome expectancies reflect the underlying belief that drugs increase personal power, sexual appeal, and social desirability—i.e. they enhance SPFit. Therefore, drug outcome expectancies reflect the basic dimension of approach (as opposed to avoidance) toward drugs and drug stimuli. Recall too, that Bolles (1972) emphasized that expectancies are what are learned in autoshaping and avoidance learning.

Distortion of the frame of reference

In humans, SPFit theory posits that a 'cognitive map' or 'frame of reference' develops concerning situations and behaviors that boost versus impair SPFit. In western culture, this map or frame is probably viewed by the individual in terms of situations or behaviors that increase (or impair) empowerment, sexual desirability or personal attractiveness rather than the biological terms of 'survival' or 'reproductive fitness'. Drug outcome expectancies develop as part of this motivational map or frame of reference. Moreover, drug experiences distort this map because they produce new 'anchors' and points of reference for the limits of subjective experience. For example, the young teenager may find that kissing or sexual petting strongly enhances feelings of sexual desirability, until they feel the artificial boost in SPFit from taking a drug of abuse such as cocaine or alcohol. Learning to drive a car is another example of an empowering experience that may pale in comparison to effects of drugs on SPFit. As a result, the frame of reference becomes distorted in drug abusers but not in non-users, in such a manner that culturally sanctioned activities that bring a sense of control and personal attractiveness are diminished relative to drug abuse. In addition, cues for drugs or positive predictors of drug availability or use become highly salient stimuli that exert increasingly strong effects on drug expectancies and drug-seeking behavior. The motivational map also reflects expectancies concerning events or behaviors that diminish SPFit, and these anchors, too can be influenced by drug use. These considerations suggest empirical tests of an important component of SPFit theory, or the distortion of the SPFit frame of reference through drug experiences and autoshaping/sign-tracking of drug cues.

This cognitive map or frame of reference for SPFit bears some similarity to Goldman *et al.*'s (1991; Dunn & Goldman 1998) idea of a distributed memory system for alcohol expectancies that differs as a function of degree of use. However, SPFit theory is couched in terms of the motivational construct of SPFit and autoshaping/sign-tracking/feature positive as a learning mechanism for these expectancies rather than of memory *per se.*

Drug wanting and drug liking

The autoshaping model (Newlin 1992, 1999) suggests a possible mechanism for Robinson & Berridge's (1993) paradoxical proposal that, as drug use escalates, drug 'wanting' (or craving) increases while drug 'liking' (reward) decreases. This is paradoxical because it suggests that drug addicts feel compelled to use a drug that provides little or no reward. If we assume there is a feed-forward characteristic of the control theory model (Fig. 2), then the increase in SPFit gradually shifts forward in time from the consummation of the drug ('drug liking') to the craving and expression of drug expectancies (drug 'wanting') in response to drug cues. These conditioned responses anticipate consummation and the drug effect, itself.

Therefore, the autoshaping model of drug craving leads to many new, testable hypotheses (above) when it is incorporated into SPFit theory.

COMPARISON OF THEORIES

In Table 3, SPFit theory is compared with a representative subset of current theoretical systems that dominate the substance abuse field.

Theory structure

Behavioral pharmacology is dominated by the ideas and experimental methods of Skinner (1938) and his followers. The central metaphor of this model is drug self-administration in animals (Pickens & Thompson 1968), and in humans (Griffiths, Bigelow & Henningfield 1980), which represents an enormous and compelling experimental literature. Behavioral pharmacology and Pavlovian (Pavlov 1927) models are 'bottom-up' theories in that they posit basic, simple mechanisms of learning (e.g. response-contingent and stimulus-contingent conditioning, respectively) and a set of primary reinforcers (e.g. water, food, sex, abused drugs). Complex behavior represents combinations of these basic processes.

In contrast, SPFit theory is a 'top-down' model. It posits basic survival and reproductive motivations at the top of a hierarchy of motivated behaviors that become

Table 3 Comparison of SPFit with major theories of substance use disorders.

Theory	*SPFit theory*	*Behavioral pharmacology*	*Pavlovian conditioning*	*Cognitive*	*Neuroscience*
Theoretical foundation	Evolutionary biology, psychopharmacology	Skinner	Pavlov	Connectionism	Biological reductionism
Central metaphor	SPFit	Drug self-administration	Affective learning	Biocomputer	Neural signaling
Organization	Top-down (hierarchical)	Bottom-up	Bottom-up	Top-down	Functional pathways
Empirical foundation	Common factors, acute drug effects, autoshaping, sign-tracking	Drug self-administration	Cued responses	Cognitive work-load	Neuropsychopharmacology
Motivation	Survival and reproduction	Skeletal learning	Visceral learning	Non-specific, habit	Biological
System architecture	Hierarchical modules	Linear positive feedback	Linear negative feedback	Hierarchical systems	Neural networks
Associationism	Epiphenomenon	Fundamental building block	Fundamental building block	Fundamental building block	Emergent property
Hedonism	Epiphenomenon	Building block or epiphenomenon	Affective dynamics	Epiphenomenon	Epiphenomenon
Nature of reward	False information re. survival and reproduction	Mechanistic	Mechanistic	Representational	Mesolimbic dopamine
Cortico–mesolimbic dopamine	Survival and reproductive system	Reward center	Reward center	Not applicable	Reward pathway
Tolerance and sensitization	Building blocks	Side effects	Learned responses	Cognitive adaptation	Physiological regulation

less directly related to survival and reproduction as they move down the hierarchy. Survival is primary, reproductive fitness is secondary, and all other functions are tertiary or lower in their priorities. The current theory is very specific about the nature of motivation in general (i.e. to survive and to be reproductively fit) and the motivation to abuse drugs in particular (i.e. to achieve an artificial sense of heightened SPFit). Other theories are much less specific about the motivation to take drugs. However, all theorists—when pressed—might agree that humans and other animals generally behave in a manner that promotes their survival and reproduction.

Nature of reward

The basic postulate of behavioral pharmacology is that abused drugs are primary reinforcers—that is, they are inherently 'rewarding', even in naïve animals (and humans). SPFit theory postulates that abused drugs are self-administered by animals because they activate the CMDA system directly, which artificially engages the basic motivations of survival and reproductive fitness. In humans, drug self-administration produces a temporary and false enhancement of SPFit, the primary function of the CMDA system.

Associationism and hedonism

In contrast to behavioral pharmacology, Pavlovian and cognitive theories, SPFit theory is not based on the intellectual traditions of associationism and hedonism, which are considered largely epiphenomenal. In the current theory they are viewed as secondary at best, rather than as non-existent. Both behavioral pharmacology and psychodynamic theories incorporated associationism and hedonism as fundamental building blocks for their theories.

Cognitive theories

Cognitive theories have some structural similarities to the SPFit theory in that they: (1) are hierarchical and 'top-down' in organization, (2) emphasize non-linear systems such as might be modeled in neural network computation or parallel distributed processing and (3) take an informational rather than a mechanistic approach to motivation and reward. The most important difference between SPFit theory and cognitive models concerns their respective reasoning about motivation. In contrast to SPFit theory, cognitive theories are often silent on the nature of motivation. Cognitive science in general has not been a fertile ground for models of motivation, which were dominant at one time in psychology. Moreover, cognitive approaches usually fail to incorporate what is known about biological (i.e. brain) substrates of drug-

seeking behavior. For example, Tiffany's (1990) cognitive theory of drug craving describes well the cognitive workload associated with craving, and it delineates a habit theory of drug use. However, his theory does not address the motivation to use drugs and to crave them, or the neurophysiological mechanisms that control this behavior. Cox & Klinger's (1988) cognitive model of alcohol use describes the decision-making process when a person decides to use or not to use a drug, but is silent on how the cognitive outcome expectations about the drug develop and the brain processes that control these expectancies. Therefore, cognitive theories of substance abuse often seem like 'trains without locomotives'.

A second difference between cognitive theories of SUD and SPFit theory is that, not surprisingly, cognition is considered primary in cognitive models, but in SPFit theory it is viewed as 'cognitive overlay' or elaboration of more fundamental motivational processes. A third difference is that cognitive theory views the brain as a general-purpose biocomputer in much the same way that physical computers are almost endlessly flexible in their processing functions. In contrast, SPFit theory adopts the view from evolutionary psychology (Barkow, Cosmides & Tooby 1995) that the brain is highly specialized: it is organized and functions to promote survival and reproductive fitness-that is, SPFit. A general-purpose computer or biocomputer is not self-promoting.

Neuroscience

Neuroscience approaches to SUD are not so much theories as they are empirically based systems of research. Over the last decade, neuroscience has achieved an ascendent role in SUD research with rapid, cumulative findings on brain mechanisms of SUD (Wise 2000). Models of the CMDA have progressed from a 'one neuron brain' (dopamine neurons with cell bodies in the ventral tegmental area extending to synapses in the nucleus accumbens) in the mid-1980s to the highly interconnected and subregionally specific models that are current. Neuroscience is governed by biological reductionism in which behavioral and cognitive functions are related to specific functional neural pathways.

In neuroscience, constructs such as motivation or associationism are viewed as 'emergent properties' of neural systems. Importantly, the neural system is viewed as prepotent rather than the behavioral properties that emerge from their operation. Therefore, characteristics such as 'reward' and 'reinforcement' are related to functional dopamine pathways, which are sufficient to describe their properties. SPFit could be viewed as an 'emergent property' of the CMDA, although SPFit theory views SPFit as the prepotent explanatory construct over the neuropharmacology of its biological substrate.

These theoretical comparisons support the view that SPFit theory is novel and unique.

CORTICO–MESOLIMBIC DOPAMINE SYSTEM (CMDA)

The third major concept in SPFit theory is a critical revision of the 'reward center' and 'surrogate stimulus' (Di Chiara *et al.* 1993) models of the CMDA. The current theory holds that the CMDA system is, in fact, a basic survival and reproductive function system. Specifically, it is not a 'reward center'. In humans, the CMDA is the proposed brain substrate for SPFit (SPFit is not defined in non-human animals). The finding that stressful and novel stimuli activate the CMDA is fundamentally inconsistent with the prevailing notion that this brain system is a 'reward center' or even a 'reward pathway'. However, this evidence is quite consistent with the view that the CMDA is a basic survival and reproductive center. That is—stressful stimuli would be expected to produce pronounced activation of survival functioning, as long as the stressful stimuli were not so prolonged or so uncontrollable that the animal 'gives up' and CMDA function is depressed below baseline levels.

The 'surrogate stimulus' model could potentially account for these dynamics if stressful stimuli were added to the list of 'surrogates', although this would be tantamount to adopting the current view of the CMDA as a survival and reproductive motivation system.

Extracellular dopamine in nucleus accumbens

Di Chiara & Imperato (1988) reported that a number of abused drugs preferentially increase dopamine efflux in the nucleus accumbens of conscious, freely moving rats. This and many more studies with additional abused drugs led to speculation that a major 'reward center' in the brain for drugs of abuse had been found. This apparent finding of a new, physiological common factor seemed to fit well with notions of reinforcement theory and the so-called 'dopamine reward hypothesis' of substance abuse. These conclusions were unabashedly simplistic in accordance with parsimony.

Aversive stimuli

Several lines of evidence have developed over the last decade that challenge this interpretation. First, aversive stimuli, such as footshock (Sorg & Kalivas 1991, 1993) and tail pinch (see Salamone 1994) and other stressors (Kalivas & Duffy 1989), also increase dopamine efflux in the nucleus accumbens, a finding that appears inconsistent with the view of this brain structure as a 'reward center.' Secondly, there is cross-sensitization between

aversive stimuli and drug stimuli (Sorg 1992; Prasad, Ulibarri & Sorg 1998) such that effects with opposite hedonic valences seem to augment each other. Moreover, stressful stimuli have been found to reinstate drug-seeking behavior after extinction of self-administration (Ahmed & Koob 1997; Shaham & Stewart 1995; Erb, Shaham & Stewart 1996; Piazza & Le Moal 1998). A particularly dramatic finding is that rats will self-administer corticosterone (Piazza *et al*. 1993). This may reflect the need for the organism to be motivated because that is inherently adaptive. Also, there is evidence that morphine injections overcome 'learned helplessness' phenomena (Besson *et al*. 1998).

Micro-injections of various abused substances into the mesolimbic area elicit a variety of motivated behaviors, such as foraging/feeding, sexual behavior and other approach behavior (Kalivas & Samson 1992; Newlin 1994; Salamone 1994). It is not at all clear why activation of a 'reward center' would lead to new motivated behavior upon which the microinjections were not contingent. In addition, the temporal patterns of accumbel dopamine changes during drug self-administration are complex (Gratton & Wise 1994; Wise *et al*. 1995; Ranaldi *et al*. 1999) and are not readily interpretable in terms of reinforcement or reward. Also, the amplitude of dopamine increases in nucleus accumbens depends critically on whether the animal is self-administering the drug or is receiving the same injections passively in a yoked control condition (Dworkin, Mirkis & Smith 1995; Hemby *et al*. 1997). A 'reward center' would not be expected to respond differentially to passive versus active administration of drugs, while a survival and reproductive fitness system would be.

Novelty

Accumbel dopamine is also very sensitive to novel environments (Salamone 1994; Ikemoto & Panksepp 1999), a finding that is inconsistent with notions of 'reward pathways'. However, the animal exposed to a novel environment must assess whether it is hostile (a threat to biological fitness) or an opportunity to enhance fitness. Although not rewarding, a novel environment is a biologically relevant stimulus in the sense that mobilization of resources is needed to maximize the positive (increased fitness) in that environment or to minimize the negative (decreased fitness) if it is threatening. In humans, novel environments are an opportunity to enhance SPFit or to protect SPFit if the environment is hostile.

Drug effects without rewarding subjective effects

In support of the notion that rewarding subjective effects are incidental or secondary to increased SPFit, there are a number of instances in which there are measurable drug effects or drug self-administration in the absence of positive subjective effects. The most common example would perhaps be nicotine. The 'euphoria' from smoking cigarettes is minimal at best in many addicted smokers as they smoke freely at their own pace. This is normally attributed to very strong tolerance to the subjective effects of nicotine, but it begs the question of the role of reward or euphoria in habitual use. Lamb et al. (1991) noted a dissociation between the subjective effects of morphine and self-administration in nonaddicted subjects with histories of heroin abuse. At a low dose of morphine, volunteers continued to self-administer the drug in a fixed ratio—100 schedule of reinforcement despite reporting no subjective effects. A number of studies (Muntaner *et al*. 1989) have found similar results with low doses of cocaine—that is, self-administration in the absence of euphoria or other rewarding subjective effects. Therefore, it may be concluded that the experience of rewarding subjective effects is not a necessary condition to support drug-taking behavior.

Directed behavior

These are all empirical findings that are difficult to reconcile with the notion of the CMDA as a reward center, but fit comfortably with the current view that the CMDA is a basic survival and reproductive behavior system. Moreover, this motivated behavior is highly directed toward (or away from) the biologically relevant (that is, relevant to survival or reproduction) stimulus; it is not merely adjunctive behavior that has no clear biological function. In studies of low-dose locomotor activation (Wise & Bozarth 1987), the behavior may appear undirected simply because the animal is typically alone in a bare cage with no discrete stimuli to which it can direct the biologically relevant behavior. It would be useful to determine the animal's choice of directed behavior in a test of low-dose locomotor activation when the animal has a variety of discrete stimuli in the test chamber that may indicate the nature of the directed behavior. For example, would a male rat be more likely to mount a receptive female, or huddle with other rats in a cool environment, or attack a common prey after they have received low doses of a specific drug of abuse?

The view that CMDA is a reward pathway is still current (Grace 1995; Koob & Nestler 1997; Berridge & Robinson 1998; Di Chiara 1998; Robbins & Everitt 1999; Sutton & Beninger 1999). However, some recent reviews of the literature have attempted to incorporate evidence of CMDA involvement in aversive motivation into new ideas about the functional roles of this system. For example, Salamone (1994) concluded that CMDA is involved in both appetitive and aversive motivation, and

Ikemoto & Panksepp (1999) suggested that nucleus accumbens dopamine is 'an incentive property constructor', and it has a role in both 'invigoration' and incentive learning. These roles are not limited to reward learning, nor are they directly related to positive hedonic effects of drugs (Ikemoto & Panksepp 1999). However, theorists, including Nessa & Berridge (1997), have not viewed the CMDA as a survival-reproductive motivation system.

Behavioral control

Cabib & Puglisi-Allegra (1996) reported that dopamine outflow in the nucleus accumbens is increased by controllable/escapable stressful stimuli, but decreased by uncontrollable/inescapable stressors. This finding is again consistent with the notion that the mesolimbic dopamine system controls survival and reproductive motivation rather than being a simple reward center. Escapable stress would be expected to enhance active motivational processes, while prolonged inescapable stress would be expected to reduce motivation profoundly. It would be difficult to argue that an escapable stressor is in some way 'rewarding', but it is clearly motivating. Escapable stress would be expected to strongly activate basic survival functioning; in contrast, inescapable stress, if sufficiently prolonged, would suppress these same functions as the animal 'gives up' and adopts more primitive defenses such as freezing.

Drive?

Therefore, we might amend our notion to suggest that the mesolimbic dopamine system is a physiological substrate for motivated behavior relevant to basic survival and reproductive functions. We might have concluded that it is a non-specific 'GO' center (as opposed to a 'NO-GO' center) or 'drive' (Ikemoto & Panksepp 1999) system, but this fails to capture the highly directed nature of the behavior. SPFit theory predicts that animals that are administered drugs of abuse will exhibit specific, directed, goal-oriented behavior toward biologically relevant (i.e. relevant to survival or reproductive fitness) stimuli if such stimuli are physically present in their environment. This prediction contrasts markedly with the notion of CMDA as a non-specific 'GO'or 'drive' system that is engaged by abused drugs.

MODULARITY OF MIND

The concept of modules of mind (Fodor 1983) is a controversial theory that has been applied to comparative cognition and behavioral ecology (Boysen & Capaldi 1993; Gallistel 1991). This concept was discussed originally in relation to cognitive-perceptual modules that preprocess sensory information into informational units such as phonetics, which are useful to higher levels of cognition (e.g. syntactic or grammatical processing). Fodor's (1983) argument was that perceptual modules are primarily hard-wired, domain-specific, informationally encapsulated, and impermeable.

In Fodor's (1983) theory, modules may be classified as either horizontal or vertical. Vertical modules, such as phonetic and grammatical processing, are both domain-specific and informationally encapsulated. They become automatic and difficult to interfere with (i.e. impermeable).

SPFit theory proposes that mammals and humans have evolved a vertical module—the CMDA—that controls the motivation to survive and reproduce. This module is assumed to be partially hard-wired in the sense that the propensity for behavior directed toward survival and reproduction is transmitted across generations through traditional Mendelian processes. Moreover, there are individual differences in this motivational system that are genetic, and these hard-wired differences are central to an evolutionary process because genetic variation forms the basis for natural selection.

The SPFit motivational module is domain-specific inasmuch as it is engaged only by environmental stimuli (such as drug paraphernalia) that are perceived as relevant to survival and reproductive functions. This module is informationally encapsulated in the sense that it is only partially accessible to verbal self-report in humans, depending on the extent to which the specific culture endorses concepts that are directly relevant to SPFit.

Finally, the concept of impermeability refers to the observation that by the time functions associated with vertical modules, such as SPFit, are learned, they become highly automatic and surprisingly resistant to extinction. Impermeability may underly the compulsive nature of addiction and the very high relapse rates following cessation of drug use in SUD.

EMPIRICAL FALSIFIABILITY

A large amount of existing data are consistent with SPFit theory, some of it uniquely fitting the theory. It was noted above that effects found with aversive and novel stimuli support the conclusion that the CMDA system and its many neurophysiological connections is a survival and reproductive motivation system. Evidence that there are situations in which people self-administer drugs with no measurable subjective effects (euphoria) are inconsistent with the view that the CMDA is a 'reward pathway', but fit comfortably with SPFit theory. The pioneering work of McClelland (1974) and Wilsnack (1974) on the effect of

alcohol drinking on power motivation, sex differences, and self-esteem are perhaps uniquely explained by SPFit theory. Autoshaping has been demonstrated with alcohol (Krank 1992) and cocaine (Carroll & Lac 1993, 1997, 1998) as the unconditioned stimulus.

In addition to existing data, SPFit theory makes a number of very specific predictions that would require the theory to be modified or abandoned if they were falsified. First, SPFit should be amenable to reliable and valid measurement, and it should not be redundant with self-efficacy or positive affect. Acute administration of drugs of abuse should increase SPFit, and drug withdrawal should decrease SPFit. For drugs with biphasic effects (whether as a function of the slope of the drug blood curve or of dose), this should be mirrored in biphasic effects on SPFit. These effects should depend on the risk status of the subjects, with high risk individuals showing larger effects of acute administration and more pronounced biphasic effects. The effect of drug cues should be to produce a transient increase in SPFit when the drug is available, and a decrease in SPFit when it is not. In experimental users of drugs, the increase in SPFit should occur to the drug effect, but in established drug users, it should occur more to anticipatory drug cues rather than to the drug, itself (see SPFit analysis of Robinson & Berridge's 1993 theory, above).

There is a specific set of predictions concerning drug craving and outcome expectancies. For example, craving should be associated with a distorted cognitive map or frame of reference for behaviors and situations that increase and decrease SPFit, compared to individuals who do not use or crave drugs. During experimental use of drugs, the distortion of these maps should be apparent in longitudinal studies, with progressively diminished salience to behaviors and situations for increasing SPFit that are culturally sanctioned, and new psychological 'anchors' for the limits of experience provided by the acute effects of abused drugs. In addition, craving and drug outcome expectancies should be correlated. Drug cues should lead to approach behavior (through autoshaping) and left frontal brain activation, only among established drug abusers and particularly when the drug is available.

A final prediction is that SPFit should have both significant heritable and environmental components. The latter could be examined by studying families in which one or both adoptive, foster, or step parents have an SUD, compared to similar families without SUD (Newlin *et al*. 2000).

Although SPFit theory makes many testable (i.e. falsifiable) empirical predictions, some aspects of the theory are frankly speculative. For example, there is abundant evidence that the CMDA is not a reward center (summarized above), but until SPFit can be measured validly, the construct is not well grounded in empirical research. SPFit appears to have some characteristics of Fodor's (1983) vertical module, but the various criteria for a vertical module have not been substantiated. Autoshaping with alcohol and cocaine as the unconditioned stimuli has been observed, but the critical test of preventing the animal from consuming the drug if it shows directed behavior toward the conditioned stimulus has not been performed. Therefore, this new theory is presented in order to provide a conceptual framework for existing data and to suggest interesting empirical tests that can falsify it. In many cases, these new studies would not be performed had this theoretical proposal not been advanced.

CONCLUSION

This discussion has focused on four concepts that, taken together, comprise SPFIt theory: SPFit, reformulation of the functional role of the CMDA, autoshaping/sign-tracking/feature positive and modularity of mind. Leshner (1997) suggested that the SUDs are 'chronic, relapsing disorders of the brain', and that the addictive process is 'like a switch being thrown in the brain'. SPFit theory proposes that the motivation to artificially enhance SPFit is a factor that is common to experimental use, escalating abuse, addiction and relapse to drug-taking behavior. This contrasts with most theoretical models of SUD's, where initiation and experimental use are thought to be related to peer influence and drug availability, escalating use to genetic vulnerability, addiction to unclear biological mechanisms and relapse to conditioning or other psychological factors. In SPFit theory, the motivation is the same throughout the course of the disorder—to artificially boost SPFit.

The psychobiological mechanism by which the substance abuser learns that drugs will enhance SPFit (throwing the 'brain switch') is similar to autoshaping as the user learns that drug use is an easy, reliable means to enhance SPFit. The neurophysiological substrate of this disorder of the brain is the CMDA and its modulating connections. SPFit and the CMDA have been likened to a vertical module (Fodor 1983) for survival and reproductive motivation with formal characteristics that make it relatively impervious to interference. In humans, the acute effect of abused drugs is to artificially elevate SPFit, and craving and outcome expectancies about drugs are an outgrowth of sign-tracking/feature positive effects.

SUDs represent the hijacking of this motivational module by abused drugs. SPFit theory emphasizes puberty as a critical period in which SPFit achieves full expression, and consolidates and becomes less plastic. For this reason, young people are at particular risk for 'fixation/completion/concretization' of SPFit by drug-taking behavior. Rather than SPFit consolidating around cul-

turally sanctioned behaviors, SPFit can be hijacked by the highly reliable enhancement of SPFit by drugs of abuse.

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