European Journal of Personality
Eur. J. Pers. **24**: 404–422 (2010)
Published online in Wiley InterScience
(www.interscience.wiley.com) **DOI**: 10.1002/per.780

Discussion on 'Automatic and Controlled Processes in Behavioural Control: Implications for Personality Psychology' by Corr

OPEN PEER COMMENTARY

Mapping Personality Traits onto Brain Systems: BIS, BAS, FFFS and Beyond

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Abstract
This comment critiques Corr's (2010) characterization of the personality traits associated with the elements of Gray's conceptual nervous system: The behavioural inhibition system (BIS), the behavioural approach system (BAS) and the fight-flight-freeze system (FFFS). Most attention is paid to the FFFS because least is known about its manifestation in personality. Additionally, I suggest that Corr's framework for understanding automatic and controlled processing is useful for developing theories of the biological systems underlying traits that are not directly related to BIS, BAS and FFFS. Copyright © 2010 John Wiley & Sons, Ltd.

Personality has been defined as 'an individual's unique variation on the general evolutionary design for human nature' (McAdams & Pals, 2006, p. 204), which implies that to understand personality we must explain (1) the relevant evolved systems that are operative in every intact human brain and (2) the parameters of those systems that vary from person to person to produce personality trait differences. In relation to the first of these explanatory categories, Corr (2010) focuses on the distinction between automatic and controlled systems. In relation to the second, Corr focuses on personality traits reflecting variation in the elements of Gray's 'conceptual nervous system': The behavioural inhibition system (BIS), the behavioural approach system (BAS) and the fight-flight-freeze system (FFFS). I offer a critique of Corr's characterization of these systems and their associated traits, followed by a brief discussion of additional traits that are probably not primarily related to the BIS, BAS and FFFS and may primarily reflect controlled instead of automatic processes.

Of Gray's three systems, the FFFS has received the least empirical and theoretical attention in relation to personality, and the question of what states and traits are associated with the FFFS is far more open than one might assume from Corr's (2010) summary:

'The [FFFS] is responsible for mediating reactions to *all* aversive stimuli, conditioned and unconditioned, and is responsible for avoidance and escape behaviours. It mediates the emotion of fear, and the associated personality factor consists of fear-proneness, timidity and avoidance'.

Note that the FFFS is not responsible for *all* forms of avoidance, given that Corr identifies the BIS as responsible for passive avoidance, which is likely to be more common than active avoidance in day-to-day human life. Both BIS and FFFS serve a primarily defensive function, to prevent or correct error and avoid harm. Gray and McNaughton (2000) noted that the crucial distinction between BIS and FFFS is that the FFFS controls response to threats when the only motivation is avoidance. In those cases, avoidance can be accomplished either by active avoidance (flight) or by destruction/deterrence (fight). The BIS, in contrast, controls response to threats that one is motivated to approach. The function of the BIS most generally is to detect and resolve goal conflicts, which usually take the form of approach-avoidance conflicts. (Imporantly, however, approach-approach and avoidance-avoidance conflicts also trigger BIS, and thus simultaneous activation of BAS and FFFS is not necessary to trigger BIS—nor is it sufficient, as BAS and FFFS may be strongly activated together in pursuit of a single goal, e.g. running from a bear toward a building with a sturdy door.) Activation of the BIS serves to protect an organism motivated to approach a potential reward where danger is also present. This protection is accomplished by inhibiting (slowing or even completely stopping) the relevant approach behaviour, triggering increased attention and identification of potential threats and increasing arousal of the FFFS to allow a rapid switch to flight or fight, if threat becomes too great. Even if perceived threat never becomes sufficient to trigger a switch to behaviour governed by FFFS, a strong BIS activation may prevent any further approach to the potential reward (passive avoidance), whereas a weaker activation will allow cautious approach.

The above summary suggests that 'fear' is a problematic label for the emotional state associated with FFFS activation and that 'fear-proneness, timidity and avoidance' are probably not the best characterizations of traits associated with FFFS sensitivity. McNaughton and Corr (2004) use 'fear' to denote a specific psychological and biological state categorically distinct from anxiety. In common usage, however, the referent of 'fear' is more general—and less distinct from anxiety. What most lay people mean by 'fear' describes emotions accompanying both the active avoidance produced by FFFS and the passive avoidance produced by BIS. We say things like, 'I feared asking my boss for a raise', even if, after hesitating, we were able to bring ourselves to do so rather than panicking outside the door to the boss' office and fleeing back to our desks.

Most stimuli feared by human beings occur in situations containing potential reward (the most commonly experienced fears are probably of negative evaluations by others, in work, dating, family, friendship, etc.). BIS activation and passive avoidance should therefore be a more typical referent of 'fear', in common usage, than FFFS activation and active avoidance. Thus, Carver and White's (1994) BIS scale is not necessarily wrong to refer to 'fear' in some of its items. And 'timidity and avoidance' are traits as likely to be associated with BIS sensitivity (and with anxiety) as with FFFS sensitivity.

'Panic' is probably a better specific emotional label to use as a marker of FFFS activity in personality assessment. Most people do not panic often, which highlights a problem with Corr's assertion that, except in cases of false alarm, activation of the BIS ends when 'behavioural control reverts to FFFS-mediated avoidance/escape'. In fact, when BIS activation causes passive avoidance of some danger, one frequently neither actively flees nor fights, but rather switches to some other approach behaviour that is less threatening (*cf.* McGregor, Prentice, & Nash, 2009)—perhaps explaining the popularity of computer solitaire. The BIS has then resolved conflict not by activating FFFS but simply by suppressing the potentially dangerous goal, allowing a different goal to be pursued instead.

Thus far, I have said little about the 'fight' component of the FFFS. However, a sensitive FFFS may lead to irritability and defensive anger as well as to panic. The existence of 'anger attacks', which have physical symptoms similar to panic attacks but without the emotion of fear, is suggestive of the biological link between these affective states (Fava, Anderson, & Rosenbaum, 1990). A trait reflecting general FFFS sensitivity should encompass the tendency to be both panicky and irritable.

Such a trait can be found within Neuroticism. Factor analysis of 15 different facets (subtraits) of Neuroticism, within the Big Five model, provided evidence for a two-factor solution (DeYoung, Quilty, & Peterson, 2007). These factors were than characterized by their correlations with over 2000 trait items. The factor labelled 'Withdrawal' described people as anxious, self-conscious and depressed, whereas the factor labelled 'Volatility' described people as emotionally labile, irritable and easily upset. Withdrawal seems to encompass traits associated with passive avoidance and the functions of the BIS (the label 'Withdrawal' can refer to a withdrawal of effort from approach-oriented goals, rather than to active physical withdrawal or flight). In contrast, Volatility has promise as a possible marker of FFFS sensitivity. The existence of BIS- and FFFS-related subtraits within Neuroticism would be consistent with Gray and McNaughton's (2000) description of Neuroticism as jointly determined by the sensitivities of BIS and FFFS.

Corr's (2010) description of traits associated with BIS is unproblematic, but his assertion that the personality factor associated with BAS 'consists of optimism, reward-orientation and impulsiveness' requires a caveat. Although Gray initially identified impulsivity as the trait most likely to be associated with BAS sensitivity, research has since suggested that Extraversion is a better candidate (Depue & Collins, 1999; Pickering, 2004; Smillie, Pickering & Jackson, 2006). Individual differences in impulsivity are likely to reflect not only BAS sensivity, but also variation in the strength of the top-down control systems that inhibit prepotent responses. Impulsivity is therefore a compound trait resulting from the strengths of multiple systems (Depue & Collins, 1999; DeYoung, in press).

The existence of individual differences in top-down control systems highlights the need to go beyond Gray's conceptual nervous system in mapping traits onto brain systems. The Big Five model provides a reasonably comprehensive taxonomy of traits, as its five factors emerge when a large variety of descriptive adjectives or existing personality scales are factor analyzed (John, Naumann, & Soto, 2008; Markon, Krueger, & Watson, 2005). Two of the Big Five, Neuroticism and Extraversion, seem to encompass the personality traits directly influenced by the BIS, BAS and FFFS. The other three factors, Conscientiousness, Agreeableness and Openness/Intellect may reflect variation in systems that Corr (2010) describes as involving consciousness and top-down control. Based on the personality neuroscience literature, we have been developing theories regarding the brain systems that are involved in each of the Big Five (DeYoung & Gray, 2009; DeYoung, Hirsh, Shane,

DOI: 10.1002/per

Papademetris, Rajeevan, & Gray, 2010). The trait that seems most directly to reflect the ability to inhibit prepotent responses is Conscientiousness. In contrast, Openness/Intellect seems to reflect individual differences in the systems that govern attention and the conscious perception and manipulation of information. Both Conscientiousness and Openness/Intellect have been linked to variation in lateral prefrontal cortex (DeYoung et al., 2010; DeYoung, Shamosh, Green, Braver, & Gray, 2009). Agreeableness, which encompasses traits related to altruism, has been linked to brain systems involved in understanding the emotional and cognitive states of others. With his exploration of the interaction of automatic and controlled processes, Corr (2010) has offered psychologists attempting to explain personality in terms of brain function a useful extension of Gray's framework that makes room for additional traits.

Intersection 'Control': Bridging Cognitive and Personality Psychology

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Abstract

Corr is to be lauded for presenting a framework that serves to integrate consciousness research, dual-system thinking and self-regulation with personality psychology. Whereas I agree wholeheartedly that such a cross-cutting perspective can benefit all of these interconnected areas, here I question two more specific aspects of his approach: First, the conclusion that the lateness of conscious awareness precludes any on-line control of automatic processing and second, that the behavioural inhibition system can serve as the sole centre point of an integrative model of behavioural control. Copyright © 2010 John Wiley & Sons, Ltd.

The target article by Corr (2010) raises many fascinating issues. It is a valuable attempt to bridge areas of psychology that are typically viewed in isolation from each other by relating the distinction between automatic and controlled processing and the related issues of consciousness and volition to concepts of personality, centred on the behavioural inhibition system (BIS; e.g. Gray, 1982). Most importantly, I strongly appreciated the dynamical perspective the author advocates, as I am myself convinced that issues such as control and self-regulation can be fully understood only if the interplay of automatic and controlled processes is modelled over time.

Cognitive and social psychology are blessed with detailed accounts of dual-systems of information processing (e.g. Evans, 2008; Strack & Deutsch, 2004). In these models one system is generally seen as being responsible for the generation of automatic processing outputs (e.g. prepotent action tendencies) and the other as being in charge of behavioural control functions such as correcting these automatic processing outputs and inhibiting or overriding goal-incompatible prepotent responses. However, the relevance of these models

DOI: 10.1002/per

for personality psychology has mostly been overlooked (but see Asendorpf, Banse, & Mücke, 2002; Back, Schmukle, & Egloff, 2009; Carver, 2005; Hofmann, Gschwendner, Friese, Wiers, & Schmitt, 2008; Ouimet, Gawronski, & Dozois, 2009). Corr bridges cognitive (i.e. processing-oriented) and personality (i.e. construct-oriented) approaches in a number of innovative and unique ways. These new connections raise a number of intriguing issues. I will try to outline two that have entered and haunted my own consciousness upon reading this work.

HOW LATE IS TOO LATE?

Corr brings to our attention what he refers to as the 'lateness-problem' of controlled processing and of its accompanying conscious experience. The problem, if I understood it correctly, is as follows: Based on the findings by Libet (1985; 1999) we can assume that conscious experience (and its underlying controlled processes) take time to be generated (approx. 300—500 millisseconds). So, given its lateness, how can conscious experience ever exert a *causal* influence on behaviour because 'at the time of initiation and execution, all brain-behavioural processes are controlled by the automatic-reflexive system'? Corr's solution to the problem is to dismiss any direct (on-line, simultaneous) impact of controlled processing on automatic operations and the resulting behaviour execution. Rather, he posits only a distal (off-line, delayed) influence through the post-hoc adjustment of specific cybernetic weights of automatic processing 'such that when the same stimulus, that previously led to an error signal, is encountered again a different (more appropriate) reaction occurs'. The notion of controlled processing influencing future automatic processing fits nicely with cognitive research showing how the formation of conscious intentions, like water flowing down the cascades of a fountain, adjust parameters in a whole range of automatic sub-systems involved in, for instance, attention allocation, stimulus encoding, response selection and response execution (Dreisbach & Haider, 2009; Folk, Remington, & Johnston, 1992; Hommel, 2000; Miller & Cohen, 2001). Corr deserves credit for carrying this idea of control as a re-programming of automatic processing parameters deeply into the field of personality.

My perhaps overly simplistic response to the lateness problem is the argument that on-line control—the ability to overrule the behavioural implications of automatically triggered, prepotent action tendencies—is nevertheless possible and does not pose such a conundrum.[i] Given Libet is right, does the time it takes for controlled processing (and conscious control in particular) to 'build up' really preclude the on-line control of behaviour? Conscious control, almost by definition, has to set in after the to-be-controlled response tendency has been automatically activated (e.g. a craving for tempting chocolate, an urge to smoke a cigarette, an avoidance tendency not to take a seat next to a foreigner when walking down the aisle of a bus and so forth).[ii] Arguably the most adaptive function of the human brain, as Corr notes, is its capacity to monitor its own processing outputs, detect discrepancies with regard to superordinate goals and inhibit, correct or override

[i]My critique is directed at the first part of Corr's article dealing with the lateness problem of conscious awareness. In later sections, Corr himself appears to invoke the concept of behavioural inhibition in a way that, in my reading, is consistent with the notion of on-line control of current prepotent responses rather than with the notion of prospective control of future automatically-driven behaviour.

[ii]I will not discuss the option of pre-conscious or implicit control here which may serve to suppress the activation of a goal-incompatible response in the first place (hence, no more need for on-line control) and may be viewed as the result of (repeated) prior adjustments of the cybernetic weights of automatic processing in the way outlined by Corr.

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such prepotent tendencies. Surely, these control processes need time to be generated and implemented. If automatic tendencies would always discharge into action right away within a few hundred milliseconds, the neuronal adequacy implied by Libet's findings, though highly disputable (for re-interpretations, see Herrmann, Pauen, Min, Busch, & Rieger, 2008; Zhu, 2003), would indeed pose a serious problem for conscious on-line control to succeed (although note that Libet himself argued that there may still be enough processing time for a 'veto'; Libet, 1999). However, in real life, translating prepotent action tendencies into actual behaviour may often afford considerable time and opportunity as well (e.g. going to the refrigerator, unwrapping the chocolate, putting it into one's mouth, chewing and swallowing it), unless we confine ourselves on reflex-like behaviours such as removing a hand from a hot stove.[iii] This is not to deny that people may often lose the 'horse race' between prepotent action tendencies and controlled processing (Logan, 1997). More often, however, deficits in the control of behaviour may stem from a lack of appropriate standards, self-monitoring, control resources or control motivation (e.g. Baumeister & Heatherton, 1996) rather than from time constraints, and this is where individual differences may have their strongest effects.

THE BIS AND BEYOND

When speaking of a general theory of control, is it really justified to grant the BIS such a pre-eminence? There is no doubt that the BIS is involved in error detection, behavioural inhibition and the triggering of subsequent controlled information processing (see Corr, 2010). However, in order to provide a comprehensive model of control, we may have to take into account a far wider range of functions enabled by controlled processing, such as reasoning, the ('on-line') simulation of alternative behavioural plans in the face of obstacles, decision-making and other instances of complex problem-solving (e.g. Evans, 2008; Jurado & Rosselli, 2007; Strack & Deutsch, 2004). In my view, the array of processes that have been identified and in subserving cognitive control seem to better fit under the umbrella of executive cognitive functioning (ECF) rather than the BIS alone. ECF seems to be supported by a whole range of functional units in the prefrontal cortex and beyond (Collette et al., 2005; for a review, see Jurado & Rosselli, 2007). From a cognitive perspective, there appear to be at least three main components that work together in supporting executive control, and inhibition is only one of them (albeit an important one): The ability to flexibly switch between multiple processing goals, the ('on-line') maintenance and updating of goal-relevant information in working memory, and mechanisms of attentional and behavioural inhibition (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Smith & Jonides, 1999). Mapping reliable individual differences in these components more strongly onto personality constructs and real behaviour is clearly an important task that may help to further strengthen the bond between the two disciplines that Corr has set out to intensify.

ACKNOWLEDGEMENT

This article was supported by a grant from the German Science Foundation (HO 4175/3-1).

[iii]On a more general level, theories of control should not only focus on the influence of controlled processing on automatic processing, but also on the reverse pathway, i.e. how automatic processing outputs (e.g. a need-driven motivation to approach a goal-incompatible object) may sometimes inhibit or 'override' people's conscious control goals (see Kavanagh, Andrade, & May, 2005, for an ingenious example).

DOI: 10.1002/per

The Redundancy of Consciousness for Personality Models

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Abstract

Corr's thought-provoking analysis of the role of consciousness in cognitive control raises important issues for personality psychology. However, the case has not been made that consciousness is an essential explanatory construct for personality theory. The definition of consciousness may be too vague for it to be useful in unraveling the time-course of control processes. Indeed, consciousness may be redundant in relation to the increasingly detailed processing models provided by contemporary cognitive neuroscience. Copyright © 2010 John Wiley & Sons, Ltd.

Philip Corr's target article provides an invaluable contribution to personality theory through its discrimination of multiple levels of control that may support stable individual differences in behaviour and subjective experience. Whether or not one agrees with its conclusions, Corr has pinpointed key issues of debate whose resolution will shape future personality theory. Here, I will take issue with Corr's emphasis on consciousness. I will suggest that it may be redundant and potentially confusing for explanatory model building.

HOW MUCH DOES CONSCIOUSNESS MATTER?

Corr proposes that, even if we set aside the 'hard problem' of consciousness, the construct remains pivotal for understanding personality. It is stated (p. 12) that we must reject the view that 'consciousness is created alongside certain types of brain information processes, but lies outside the causal chain by which such processing produces behaviour'. I remain to be persuaded that consciousness has causal force. Why can we not explain behaviour solely on the basis of a neural and/or cognitive architecture of automatic and controlled processes, as specified by extant theories executive control (Matthews, Gruszka & Szymura, 2010a)? Indeed, the 'holy trinity' of behavioural control cited by Corr on p. 37 is familiar from the processing models of the 1980s; the Norman and Shallice (1986) model, in particular, captures many of the features of control models elaborated in the target article, without assigning causal powers to consciousness.

The 'lateness' problem may be no more than a recognition that processes operate over different time scales, and with a granularity that is finer than 'fast' versus 'slow'. For example, the Norman and Shallice (1986) model allows for real-time crosstalk between parallel streams of processing, and the detailed examination of specific tasks reveals a complex temporal dynamics (e.g. Sigman & Dehaene, 2008). The (perhaps excessively punctate) model illustrated in Figure 2 may be too restricted in assuming that modification of processing weights or parameters only affects processing of future stimuli. Evidence from studies of priming (Eimer & Schlaghecken, 2002; Neely, 1991) suggests a role for controlled processing in modifying lower-level processing 'online'. Indeed, even rapid motor actions such as swinging a table tennis bat (Bootsma & van Wieringen, 1990) or

DOI: 10.1002/per

steering a vehicle (Cloete & Wallis, 2009) remain under rapidly-operating feedback control, although control is not necessarily conscious. If we view behaviour as reflecting a continuous perception-action cycle, top-down processes, including controlled attention, expectancy and preparedness, play a fundamental role in directing action (Neisser, 1976).

A related issue is the vagueness of 'consciousness' as a construct. As Dehaene, Changeux, Naccache, Sackur, and Sergent (2006) discuss, consciousness may variously refer to a global mental state, to consciousness *of* a specific object or to a preconscious state in which information is potentially available but not currently accessed by top-down attention (as evidenced by the attentional blink phenomenon). Tellingly these authors (p. 207) include a section on 'Why attention and consciousness are different'. Gray's model, as described by Corr (p. 14), appears to introduce yet another sense of the term, as a system of mental representation. Clarification of the construct would be helpful.

SOME DANGERS IN SIMPLE STATEMENTS ABOUT COMPLEX CONSTRUCTS

I have already referred to the ambiguities of 'consciousness'. The terms 'personality' and 'emotion' are also vulnerable to over-simplification. Corr (p. 36) states that 'Extraversion is another example of, largely, automatically-elicited preferences'. The comment disregards the evidence that expression of extraversion is distributed across multiple, independent processes, both automatic and controlled (Matthews, 2008, 2009). Certainly, some of the effects of extraversion can be explained by individual differences in parameters of automatic processes, as illustrated by an exercise in connectionist modelling (Matthews & Harley, 1993). Others cannot; extraversion is associated with a host of high-level social-cognitive constructs including self-efficacy, social motivations and strategies for coping and emotion-regulation (Matthews, Deary & Whiteman, 2009). If we want to say that some specific expression of extraversion is mediated solely by automatic processes, rather more evidence is required.

The assertion (p. 33) that emotion has no direct causative effect on behaviour is also questionable. We must in any case unpack the broad-based term 'emotion'. The distinction that contemporary theory makes between subjective 'feeling states' and the neurological, cognitive and behavioural components of emotion is certainly apposite. A multi-levelled perspective will assign different causal roles to different components. Indeed, even cognitive appraisal is best modelled as dynamically interacting multiple processes operating over different time spans (Scherer, 2009). In fact, the review by Baumeister, Vohs, DeWall and Zhang (2007) that Corr cites, is highly selective in its treatment of the emotion literature. It focuses primarily on complex social behaviours, which we would expect to show subtle interdependencies with emotion, rather than a simple causal effect, as expressed by the 'mood-as-input' hypothesis (Marsza-Winiewska & Zajusz, 2010; Martin & Stoner, 1996). Baumeister et al. (2007) ignore studies suggesting emotion effects on cognitive processing in paradigms such as priming (Storbeck & Clore, 2008) and selective attention (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007), although such studies have their own theoretical ambiguities over the role of automatic and controlled processes (Matthews & Wells, 2000). Recent work in my laboratory shows that measures of subjective state (task engagement) are predictive of future information-processing and sustained performance, consistent with a cognitive resource theory (Matthews, Warm, Reinerman, Langheim, Saxby, 2010b; Matthews,

DOI: 10.1002/per

Warm, Reinerman, Langheim, Washburn, & Tripp, in press c). Both Corr and Baumeister et al. (2007) advance theory by describing how emotion modulates feedback processing so as to influence future processing. The case that this is the *only* process sensitive to emotion has not been made.

CONCLUSION

Consider a different methodological stance to Corr. If the goal is to model individual differences in behaviour (as opposed to subjective experience), forget consciousness as an explanatory construct. Use the latest understanding of cognitive neuroscience to build and test detailed models of performance of key tasks, such as executive function tasks, specify parameters that may vary across individuals, and explore their relationship with personality traits (Matthews & Harley, 1993). Strength-based processing models (e.g. Norman & Shallice, 1986; Schneider & Detweiler, 1988), including connectionist models, readily accommodate both automatic and controlled processes, as well as specific processing functions, learning and error-correction mechanisms. How will this approach fail? The question for Corr is to specify what standard cognitive neuroscience models lack that a separate 'consciousness' construct provides.

Controlled-Reflective Processes Arise from Integrative Action-Goal Selection in the Ventral Pathway

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Abstract

In the spirit of Corr's integrative approach, we attempt to advance understanding of behavioural control by bringing into the discussion conclusions from diverse areas of research, including research on ideomotor processing, the ventral versus dorsal streams, and consciousness. We conclude that behavioural control arises from the ability of the ventral thalamocortical pathway to carry out integrative action-goal selection (as when holding one's breath). Because of the crosstalk capacity of consciousness, such action selection takes into account the inclinations from multiple actional systems, systems with different agendas and bases of knowledge. Copyright © 2010 John Wiley & Sons, Ltd.

A challenge faced by the human nervous system is that, under some circumstances, some of its component systems may have different skeletomotor inclinations (i.e. 'action goals') toward the same stimulus situation. (An 'action goal' is best defined by Skinner's conception of an *operant*; Skinner, 1953.) As in the classic research by Neal Miller (Miller,

DOI: 10.1002/per

1959), under conditions of conflict, one system may want to approach a stimulus while another system may want to avoid it. For example, one system may be inclined to drop a hot dish that one is carrying from the kitchen to the dinner table, but another system may desire to continue carrying it. These systems often have different agendas, operating principles, phylogenetic origins and bases of knowledge. We agree with Corr that it is fruitful at this stage of understanding to focus on the inter-goal dynamics among basic systems. Corr mentions the example of the struggle between the *fight-flight-freeze* (FFFS) and *behavioural approach* systems (BAS), as when risk-aversion conflicts with risk-proneness. Perhaps a more basic conflict occurs when, while holding one's breath underwater, one is inclined to both inhale and not inhale (Morsella, 2005). Although substantial evidence from diverse sources, including research on motor control (Grossberg, 1999; Rosenbaum, 2002) and the properties of the dorsal visual processing stream (Goodale & Milner, 2004), reveals that online motor control (e.g. visuomotor control) and other forms of action can occur unconsciously (Morsella & Bargh, in press), it has been proposed that resolving such skeletomotor *action-goal conflicts* requires the instantiation of phenomenal states (the most basic form of consciousness[1]), because the primary function of these states is to resolve such conflicts by permitting crosstalk among actional systems (Morsella, 2005). Accordingly, it has been proposed that the primary function of phenomenal states is to integrate processes that would otherwise be independent (Baars, 2002; Dehaene & Naccache, 2001; Merker, 2007; Morsella, 2005).

As reviewed by Corr, from this standpoint, phenomenal states allow for information to be brought together in some sort of workspace, one whose contents are broadcasted globally. One limitation of this *integration consensus* (Morsella, 2005) is that it fails to specify which kinds of information require phenomenal states for integration and which kinds do not. One framework proposes that phenomenal states are necessary to integrate only certain kinds of information. From this standpoint, these states are necessary, not to integrate perceptual-level processes (as in intersensory conflicts), but to integrate conflicting action-goal inclinations toward the skeletal muscle system, as captured by the principle of *Parallel Responses into Skeletal Muscle* (PRISM; Morsella, 2005). In this framework, incompatible skeletomotor plans must trigger strong changes in consciousness (see evidence in Morsella, Gray, Krieger, & Bargh, 2009a). Conversely, conflicts occurring at other stages of processing (e.g. intersensory conflicts), or not involving skeletal muscle, do not lead to such changes (Morsella et al., 2009a; Morsella, Wilson, Berger, Honhongva, Gazzaley, & Bargh, 2009b). Without these states and the crosstalk they establish, action can be influenced by one system or another (as in the case of 'un-integrated' actions such as reflexive inhaling or pain withdrawal), but it cannot be influenced by more than one system simultaneously (as in the case of 'integrated actions' such as holding one's breath; Morsella & Bargh, in press). Other effector systems, such as smooth muscle, do not suffer from this form of multi-determination and do not feature this crosstalk solution; hence, conflicts occurring outside of the skeletal muscle system (e.g. involving the pupillary reflex or peristalsis) do not require conscious mediation and are not associated with changes in consciousness (Morsella et al., 2009a). Resolving action-goal conflicts often requires top-down cognitive control, the machinations of which may not always be

[1]Referred to as subjective experience,sentience,and awareness,the phenomenal state has been best defined by Nagel (1974), who claimed that an organism has phenomenal states if there is something it is like to be that organism-something it is like, for example, to be human and experience pain, breathlessness, or yellow afterimages.

DOI: 10.1002/per

consciously accessible (Crick & Koch, 2000; Morsella, 2005), in line with the view that cognitive control and consciousness are distinct brain processes (*cf*., Koch & Tsuchiya, 2007).

Regarding behavioural control, it is important to appreciate that, unlike frameworks in which there is some kind of supervisory system (Angell, 1907; Norman & Shallice, 1980), in this framework there is no homunculus-like agent in charge of suppressing one action in order to express another action, consistent with the view that 'no single area of the brain is specialized for inhibiting all unwanted actions' (Curtis & D'Esposito, 2009, p. 72; see similar account in Kimberg, D'Esposito, & Farah, 1997). For example, in the morning, action plan *A* may oppose plan *B*, and in the evening plan *C* may conflict with *D*, with there never being the same third party (a homunculus) observing each conflict. (There are both *a priori* and empirical grounds for arguing against the existence of such a homuncular-like supervisory system; Kimberg et al., 1997). Corr and others (e.g. Libet, 2004; Passingham, 1995) focus on suppression/inhibition as a cardinal feature of behavioural control. It is true that all suppressed actions must be 'voluntary' actions (Passingham, 1995). But suppression is only one case of the kind of inter-system crosstalk furnished by phenomenal states. These states are also necessary for inter-system modulations such as 'voluntarily' increasing one's rate of inhalation in exchange for some reward. PRISM is the only framework that explains why skeletal muscles are 'voluntary' muscles: Skeletal muscle is voluntary because it is directed by multiple, encapsulated systems that, when in conflict, require phenomenal states to yield adaptive action. It is important to appreciate that 'control' mentioned by Corr is limited in that, though actions can be suppressed, their associated urges are consciously impenetrable and cannot be deactivated at will (Öhman & Mineka, 2001). Thus, control exists more at the level of overt behaviour than at the inclinations of the systems: What can be behaviourally suppressed cannot always be mentally suppressed (Bargh & Morsella, 2008).

Based on the crosstalk function of the phenomenal state, *integrated action-goal selection* can take into account the 'votes' of the often conflicting component systems. It has been proposed that the lateness of consciousness mentioned by Corr stems from the fact that phenomenal states must integrate information (which is necessary for one system to 'veto' another) from neural sources having different processing speeds (Libet, 2004). These votes can be construed as tendencies based on inborn or learned knowledge. This knowledge has been proposed to reside in the neural circuits of the ventral thalamocortical processing stream (Goodale & Milner, 2004; Sherman & Guillery, 2006), where information about the world is represented in a unique manner (e.g. representing the invariant aspects of the world, involving allocentric coordinates), one unlike that of the dorsal stream (e.g. representing the variant aspects of the world, using egocentric coordinates). As explained in *ideomotor accounts* (*cf*., Hommel, 2009; Hommel, Müsseler, Aschersleben, & Prinz, 2001), the action-goal representations that are crosstalked phenomenally tend to be perceptual-like representations of the consequences of the motor efference (e.g. the image of a finger flexing) rather than of the efference itself, which is unconscious. Accordingly, perceptual-like representations are what seem to underlie the images in dreams, episodic memory and the observations of the actions of others and of oneself. (Moreover, in subvocalization one is conscious of the perceptual-like phonological code but not of the motor-like, articulatory code.) These are the kinds of representations mentioned in analogical theories (*aka* 'embodied,' 'nonpropositional' and 'modal' theories) of mental representation (*cf*., Markman & Dietrich, 2000; see review in Morsella, 2009). (Interestingly, based on different grounds—the requirements of

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'isotropic' and 'Quinean' information processing—it has been proposed that such a perceptual-like object representation *should be* the kind of representation that is crosstalked, because, functioning as the *lingua franca* among systems, the perceptual object representation has the best 'broadcast' ability; Fodor, 1983.) This view is consistent with proposals that the function of consciousness is to construct an internal perceptual-like simulation of both the external world and of one's current place (and dispositions) within it (Hesslow, 2002; Merker, 2007; Morsella, Hoover, & Bargh, in press; Yates, 1985). Figuratively speaking, this simulacrum is like the navigational system of modern automobiles, except that representations of the organism's states and inclinations (e.g. the votes from actional systems) are also represented (Bargh & Morsella, 2008).

Consistent with Corr's proposal that action execution is largely an unconscious affair, in ideomotor theory, once an action-goal is selected (e.g. the image of pressing a button), the motor control necessary to enact the action is carried out unconsciously.[2] (This form of unconscious motor programming requires representations that are of a different nature from those involved in the unconscious priming of perceptual representations, an unconscious process that, due to the characteristics of the representations involved, has been proposed to occur in the ventral pathway; Goodale & Milner, 2004.)

Milner and Goodale (2004) propose that one way in which the ventral stream may influence the unconscious action-related activities of the dorsal stream is by top-down activation of the lower-level (e.g. retinotopic) representations that form the common source of both streams. Relevant to behavioural control, this proposal is similar to accounts regarding *indirect cognitive control* (Morsella, Lanska, Berger, & Gazzaley, 2009), in which one can indirectly influence systems that cannot be activated directly 'at will' (e.g. some incentive/affective systems; Bargh & Morsella, 2008; Morsella, 2005; Öhman & Mineka, 2001) by activating and holding in mind perceptual representations that can then stimulate the systems (Morsella & Krauss, 2004).

Within the networks of the ventral thalamocortical pathway, of the three (qualitatively distinct) forms of binding in the brain, consciousness is necessary only for one form of binding (Morsella & Bargh, in press). Conscious crosstalk is unnecessary for binding between perceptual features within or between modalities (*afference binding* as in perceptual feature binding or intersensory illusions), nor is it needed for binding between perceptual and action codes (*efference binding*; Haggard, Aschersleben, Gehrke, & Prinz, 2002), as when a subliminal stimulus elicits a correct choice-response time (Taylor & McCloskey, 1990). For example, in a choice response time task, latencies for responses to subliminal (masked) stimuli are the same as those for responses to supraliminal stimuli, suggesting that 'appropriate programs for two separate movements can be simultaneously held ready for use, and that either, one can be executed when triggered by specific stimuli without subjective awareness' (p. 62; *cf.*, Hallett, 2007). However, consciousness is required for integrating two conflicting streams of efference binding. Such *efference-efference binding* results in integrated action (e.g. holding one's breath or performing the Stroop task).

For these reasons, the 'controlled-reflective' processes discussed by Corr are associated with phenomenal states, perceptual-like representations (versus motor-codes or low-level sensory features), the ventral thalamocortical pathway, and integrated actions such as

[2]'Common code' ideomotor accounts (e.g., Hommel et al., 2001; Prinz, 1990) propose that perception and action share the same representational format, as in an 'action code' that integrates both perceptual and action components in one sensorimotor unit (Hommel, 2009). Phenomenologically, one is more conscious of the perceptual aspect of the code or unit (Grossberg, 1999; James, 1890).

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holding one's breath, winking (i.e. a voluntary blink) or suppressing a prepotent response. We agree with Corr that it is fruitful to focus on the inter-goal dynamics of primary systems, and propose that, at this stage of understanding, proposals should strive for parsimony and omit homuncular-like 'supervisory' systems (Kimberg et al., 1997). With respect to control, Lotze (1852) and James's (1890) referred not to a homunculus reining in action but rather to the influence of an incompatible idea:

According to Lotze, in order to carry out a voluntary action, two conditions must be fulfilled. First, there must be an idea or mental image of what is being willed (*Vorstellung des Gewollten*). Second, all conflicting ideas or images must be absent or removed (*Hinwegräumung aller Hemmungen*). When these two conditions are met, the mental image acquires the power to guide the movements required to realize the intention, thus converting ideas in the mind into facts in the world (Prinz, Aschersleben, & Koch, 2009, p. 38).

Stop! In the Name of Conflict: Breaking into the Heart of Behavioural Inhibition?

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Abstract

Corr argues that the behavioural inhibition system (BIS) provides executive control over automatic processes. His broad account may somewhat downplay the role of the hippocampus, thereby narrowing the range of BIS-triggering events that he considers. Recent data suggest that neurotic-anxious personality traits, reflecting the BIS, may have complex bidirectional relationships with behavioural changes triggered by BIS activation. A more precise rendering of the theory will ultimately be needed. This should include consideration of the neural mechanisms by which inhibitory signals can bring about behavioural switching. Copyright © 2010 John Wiley & Sons, Ltd.

Corr (2010) has provided a theoretical account of the roles of automatic and controlled processing in behavioural control. He considers the issues from the perspective of a personality psychologist, emphasizing the executive control functions of the behavioural inhibition system (BIS). Corr argues that part of the variance in a major personality trait (in this case anxiety-neuroticism) is caused by variations across individuals in the sensitivity of this control system.

In broad terms, I am sympathetic to Corr's analysis which is heavily influenced by the ideas of Jeffrey Gray; it is also very similar in several respects to ideas that I put forward in the 1990s. Also influenced by Gray, I wrote that behavioural inhibition 'is a form of controlled processing in which any ongoing behaviouris temporarily interrupted. The adaptive significance of this mechanism is that the delay in responding gives more time for processing the stimulus environment accurately; thereby increasing the chances of

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engaging the appropriatebehaviour [p. 155]' (Pickering, 1997). This short commentary allows only brief reflections on a few of the many nuanced ideas that Corr discusses.

At the heart of the model is the continual testing of whether the predicted and actual states of the world are in alignment (a comparator function); when a mismatch occurs then a prediction error signal activates controlled processing, which may or may not give rise to conscious awareness. What brain systems might be involved in such mismatch detection? In Gray's formulation this function was computed by the hippocampal formation (Gray & McNaughton, 2000) in keeping with animal lesion studies (e.g. Honey, Watt, & Good, 1998). Corr argues that, while the hippocampus is the main locus for detecting 'simple goal conflict', it can be detected at all levels of the extended BIS (from periaqueductal grey to the prefrontal cortex). Many well-established models of hippocampal system function, like Gray's, describe its role in mismatch detection and attentional control (e.g. Levy, 1989; Lisman, 1999; Grossberg & Merrill, 1996). These accounts show, via detailed neural modelling, how the architecture of the hippocampal system equips it for learning sequential associations and detecting mismatch (Levy, Hocking, & Wu, 2005; Lisman & Grace, 2005; Lisman, Talamini, & Raffone, 2005). It seems very unlikely that all parts of the extensive circuitry of extended BIS satisfy the quite complex neural requirements for mismatch/goal conflict detection. It would seem important to clarify whether the hippocampal formation retains the special role in the present model.

In our lab, we have studied simple associative mismatch as a means of engaging the hippocampal-system processes at the heart of Gray's BIS. A frequently-repeated sequence of neutral visual stimuli (ABCD) was interspersed with rare associative mismatch events at the end of the sequence (ABCB or ABCE). We (Dawkins, Powell, West, Powell, Pickering, 2006) studied such mismatch events when they were processed at the margins of attention while participants were focusing on and attempting a choice reaction time (RT) task. Associative mismatch produced robust inhibition (an average slowing of many tens of millisecond in choice RT). It is hard to see much goal conflict in this task setup, as the goal of the RT task remains constant throughout and the mismatch stimuli are peripheral to this goal. Indeed Corr and Gray's collaborator, Neil McNaughton (personal communication) argued it should not engage the BIS. Despite this, the size of the inhibitory effect correlated with measures of trait anxiety/neuroticism, albeit in the opposite direction to prediction (more anxiety, less RT inhibition; Pickering, Brady, Jeffs, Jones, 2001). We were able to reverse the direction of anxiety correlations if the unattended mismatching stimulus (E in the above example) was pre-experimentally conditioned to be aversive.

Related recent work from the US (Moeller & Robinson, in press) has studied RTs and behavioural predictions on trials following an error. They showed that while participants generally slowed down on the next trial after error feedback, high neurotic participants did so much more when required to make the same response on the next trial, compared with a switched response. The complementary effect was found for low neurotic subjects. This means that, after error feedback on trial n, when the same stimulus type was presented on trial n and trial $n+1$ high neurotic subjects would be faster when switching their response than when repeating it. It is not simple to explain how BIS-mediated inhibition, as described by Corr and greatest in high neurotics, would achieve this effect.

In the predictions task, participants overall tended to switch predictions more after an error on the previous trial than after a correct prediction. In this situation, high neurotic participants (rather than low neurotic participants) were the ones more likely to switch after an error, even though performance was experimentally-constrained to be at chance.

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Can all these effects be simultaneously explained by a theory of the broad kind that Corr proposes? It is uncertain; clearly, a detailed analysis of personality effects in potentially BIS-engaging processing tasks like these is needed to establish the boundaries of Corr's account.

I have suggested that Corr may have been too broad in the range of structures he proposed as being capable of detecting goal conflict, and his theory may not be able to account for the breadth of inhibitory and facilitatory effects seen with neuroticism/anxiety. Finally, it seems he may have been too specific in the consequences of the BIS error signal. Corr says that 'inhibition involves output from the BIS to whatever motor areas provided the input that generated the conflict'. How could the BIS 'know' what areas had generated the error? The error signal results whenever the predicted state of the world at time *t* and the actual state at that time are discrepant. Nothing in the wiring diagram or the accompanying text of his model allows the BIS to target its inhibition in the specific way the Corr describes. This is an example of a classic issue for neural network modelling ('the network hypothesis'; see Nigrin, 1993, p. 12). Fortunately, there are plausible neural schemes for implementing specific inhibitory effects using a nonspecific inhibition (mismatch) signal (e.g. Carpenter & Grossberg, 1990); however, these will still constrain the way BIS-mediated inhibition is likely to operate.

Further Implications of Personality and Behavioural Control

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Abstract
Theoretical explanations of personality rarely encompass as broad a range as Corr's revised Reinforcement Sensitivity Theory (RST) model, which attempts to integrate brain physiology, cognitive psychology and consciousness with personality. Yet, some of the more intriguing possibilities of the model are barely hinted at, such as the implications for the value of self-reports in personality research, or a mechanism that may be able to integrate social influence with psycho-physiology. Such extensions, along with exploration of the model's practical consequences, should take us much closer to a genuinely comprehensive understanding of personality. Copyright © 2010 John Wiley & Sons, Ltd.

Personality psychology has long had conflicts between its fundamental theory and evidentiary basis, with the empirical often winning over the conceptual but providing little to replace it. The creative and intriguing ideas of psycho-analytical, philosophical and biological thinkers are usually overwhelmed by empirical brute force of validity coefficients, such as those discussed in the often-misrepresented review by Mischel (1968), or factor analyses, which are useful but clumsy tools for theoretical work (Block, 2001). This has resulted in much of the discussion of the currently dominant lexical

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models of personality doing little more than extolling the value of describing consistencies in personality variation (Ashton & Lee, 2005), or resorting to unobservable, circularly-defined basic tendencies (McCrae & Costa, 1999). So, researchers like me, who typically use lexical personality models, find it easy to be at least a little envious of the theoretical structure that continues to develop around Gray's (Gray, 1981) Reinforcement Sensitivity Theory (RST). It was in this frame that I approached Philip Corr's extension of RST.

This extended RST model reflects an attempt to integrate broader ideas associated with reflective processing, conscious awareness and behavioural control, largely based on findings from neurocognitive research. Any attempt at explaining both personality and consciousness may seem hubristic, especially given the comments in the previous paragraph, but in several areas the argument is, if anything, not bold enough. This applies particularly to the limitations on self-awareness inherent in the proposed model and to the consideration of the model's implications for a broader understanding of personality.

One of the premises derived from the neurocognitive research upon which Corr's model is based is that our sense of conscious initiation of actions is illusory because conscious awareness comes after a decision to act, not before. It appears that awareness of act initiation is just like any other process of perception, in that it takes time to consciously perceive an event even if the event (i.e., act initiation) is internal to the observer's brain.

This premise formed much of the basis for discussing the respective functions involved in behavioural control from an RST perspective. However, the lack of awareness of processes prior to initiating action also has implications for personality measurement. Specifically, it means that when asking people to report on their propensities to act, we are asking them to observe their behaviour in a manner not too dissimilar from the manner in which people observe the behaviour of others. So, even when rating myself, I (the observer) am effectively rating me (the actor) as if I was an *other*-rater. As Corr also noted, people may also be unaware of their wants or emotions, further limiting the ability of self-raters to assess their own personality, especially the underlying processes that lead to behaviour.

Thus, Corr's integration implies that personality measurement by self-assessment will be less than veridical, and theories of personality psychology focused on 'outputs of controlled processing available to conscious introspection (e.g., self concepts) (p. 8) should be considered cautiously. Instead, this model adds strength to recent calls for greater emphasis on behavioural observation in psychology generally, and personality and social psychology specifically (Baumeister, Vohs, & Funder, 2007; Furr, 2009).

Despite this, consciousness remains crucial in Corr's model, through its role in suppressing inappropriately active impulses before they are expressed, and strengthening processes likely to be appropriate in the future. This raises yet another overlooked opportunity, namely integrating social influences with conscious processing. Even though social influence on behaviour is beyond argument, it is elided from many accounts of personality (Fleeson & Noftle, 2009), with individuals treated as closed systems. This betrays an implicit guiding assumption that individual behavioural consistencies are largely if not entirely the consequence of intra-individual phenomena. Yet humans are inherently social organisms, ones that rely on social interaction generally and linguistic interaction more uniquely for behavioural guidance. For example, it is an everyday experience for people to change their behaviour in response to a comment, such as a friend saying, 'Try doing this' or, 'I wouldn't do that'. The role of social interaction was not the focus of the article, but there is nonetheless a hint of a mechanism by which this can be

DOI: 10.1002/per

readily incorporated. Specifically, in what was little more than a side comment when discussing his model's implications, Corr suggested that linguistic interaction (specifically, 'talk therapy') may affect the proposed personality systems and consequent behaviours by verbally engaging conscious, off-line processing. Further examination of the manner in which social and especially linguistic interactions affect behavioural controls would add greatly to the value of this model by broadening its theoretical range and generalizability.

A final suggestion for this model is to consider further its practical implications. Personality is inherently an applied science because all humans are in the business of recognizing and getting the best out of the personalities of ourselves and those around us. As inadequate as it may be in many regards, one of the pleasures of the Freudian approach to personality processes is that it allows the cognoscenti to recognize patterns of behaviour that correspond to psychoanalytic processes, enhancing one's sense of awareness. Being able to recognize projection, denial and splitting serve practical purposes as well, not only in counselling and therapy but also in organizational development (e.g., de Vries, 1991). Even the theoretically-impoverished lexical models of personality are easier to discuss and apply than concepts like BIS. Integrating RST with consciousness and behavioural control theory is one thing, but it will lack something until people are able to apply it easily to everyday inter- and intra-personal issues.

Of course, there are many missing links in as ambitious a model as this—the manner by which the various components of the model interact, how the 'cybernetic weights' are constructed and applied, the relationship to brain and somatic physiology are just some that spring to mind—but there is already much that has been addressed. The biggest challenge, however, is still to come: Where do the lexical factors fit into the picture?

Levels of Personality

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Abstract

Personality may be analyzed at three levels of information processing, the reactive, routine and reflective. Corr's target article shows that Reinforcement Sensitivity Theory (RST) is an impressive model for personality at the reactive and routine levels. We argue that RST must be expanded in order to adequately capture higher level reflective processes such as long-term goal setting and would benefit from incorporating a dynamic temporal component. By doing so, RST may have the potential to reveal causal mechanisms underlying behavioural control. Copyright © 2010 John Wiley & Sons, Ltd.

Personality is the coherent patterning over time and space of affect, behaviour, cognition and desires. This patterning may be analyzed at three descriptive levels, the reactive, the routine and the reflective (Ortony, Norman, & Revelle, 2005, Revelle, 2007, Revelle &

DOI: 10.1002/per

Wilt, 2008). Rather than proposing these three levels as completely different systems which are instantiated in the brain, we prefer to consider them as a way of describing the breadth of integration over time and space that is being analyzed. At the lowest level, *reactive* responses to stimuli are automatic and may be thought to include even a lower level, the reflexive. The time horizon is the immediate moment. *Routine* behaviours show somewhat more temporal integration and represent well learned responses to stimuli that have occurred in the immediate past (seconds to minutes) based upon expectations of the immediate future (also seconds to minutes). *Reflective* cognition and affect organize memories and feelings from the past and expectations of the future where the time horizon might be a lifetime. The distinction between levels is thus one of breadth rather than kind.

Consider John who gets up in the morning in reactive response to an alarm clock, routinely brushes his teeth, takes a shower and has breakfast while reflecting on the day's activities. If a graduate student, John might be thinking while showering about how to design a study that incorporates his most recent findings on the effect of amygdala lesions in the rat. He remembers what his graduate advisor told him when she discussed how to best present his results at a forthcoming conference to avoid embarrassment and he hopes that his performance will enhance his long-term job prospects. These reflective level feelings, thoughts and desires do not themselves result in behaviour, but by integrating prior affective experiences that were consequences of past behaviour they serve as a steering function for future behaviour.

Phillip Corr in his target article has bravely attempted to apply Reinforcement Sensitivity Theory (RST) (Corr, 2008, Gray & McNaughton, 2000, Smillie, Pickering, & Jackson, 2006) to personality at multiple levels of processing and analysis. Not only does he proffer a theoretical framework for behavioural control, but he also details the nature of the relationship between conscious awareness and the previously formulated behavioural inhibition system as well as demonstrating the fundamental importance of all these topics to the study of personality psychology.

Although mentioning the need to consider multiple levels of processing, most of Corr's analysis is at what we would call the reactive or routine level. He argues from the 300–500 millisecond delay between action and thought that cognition and consciousness are not the processes to be analyzed to understand behaviour. But a part (and unknown) amount of human behaviour is not routine nor does it happen within 500 milliseconds of an event. Successful navigation of an oil tanker requires planning at least an hour ahead. Students make plans for a day or a term, parents save for their children's college tuition for two decades, couples optimistically marry for life. That is, much of human behaviour is guided by reflective processes. Just as consciousness fulfils the momentary role of error detection as Corr suggests, so too must it assist with the resolution of longer-term problems related to the temporal integration of experience. Over longer timeframes, behaviour interacts more extensively with other aspects of personality including cognition, goals and affect. Of these, Corr seems particularly silent with respect to goals, yet a significant portion of behaviours (especially those which are conscious) are conducted in accordance with a hierarchy of goals (Carver & Scheier, 1982).

Broad personality traits such as extraversion or neuroticism are descriptive summaries of affective, cognitive and goal driven processes as they result in observable behaviour over time and space. As such, it is important to consider the temporal dynamics of actions and action tendencies. One such model, the Dynamics of Action, DOA (Atkinson & Birch, 1970), may be reparameterized in terms of Cues, Tendencies and Actions, CTA (Revelle,

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1986). In the DOA-CTA model, environmental cues for reward and punishment elicit action tendencies which in turn elicit actions. These actions may be mutually incompatible and the resulting conflict leads to one or another action being executed. Actions in turn reduce action tendencies and if reinforced, modify the cue-action tendency link. Traits may be seen as rates of change in the growth and decay of expectations, action tendencies and actions. Cognitive architectures incorporating the DOA-CTA model with a learning component inspired by RST have been implemented in simple simulations of social interaction (Fua, Horswill, Ortony, & Revelle, 2009, Fua, Revelle, & Ortony, 2010). These simulations view RST in terms of three conceptual systems that act on multiple levels of complexity and that do not require such a tight linking between behaviour and subsequent consciousness as demanded by Corr. Dynamic models such as the DOA-CTA and the control theory models of Carver and Scheier (1982), when integrated with more biologically based models such as RST, have the potential to allow researchers to look for the causal mechanisms of behaviour rather than merely generating descriptive summaries. By analogy to astronomy versus astrology, we view dynamic models as similar to causally linked star clusters and descriptive models as similar to star constellations, which are grouped together only at a superficial level. Nonetheless, the utility of constellation-like personality variables (e.g. Big 5) is evident but may be limited if we are really trying to understand personality. The theory behind cluster-like personality theories is elegant but its practical significance is still unproven.

We believe that Corr's target article shows that the RST is a powerful beginning of a general theory of behavioural control, but one that needs to be elaborated to consider multiple levels of processing as well as the temporal dynamics of action. By thinking about the functions served rather than the specific mechanisms of the three systems of RST it is possible to do so.

DOI: 10.1002/per