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On feeling in control: A biological theory for individual differences in control perception

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Abstract

This review aims to create a cross-disciplinary framework for understanding the perception of control. Although, the personality trait locus of control, the most common measure of control perception, has traditionally been regarded as a product of social learning, it may have biological antecedents as well. It is suggested that control perception follows from the brain's capacity for self regulation, leading to flexible and goal directed behaviours. To this account, a model is presented which spans several levels of analyses. On a behavioural level, control perception may be a corollary of emotion regulation, executive functions, and social cognition. On a neural level, these self-regulatory functions are substantiated in part by the dorsolateral and ventral prefrontal cortex and the anterior cingulate cortex. In addition, a possible role of subcortical-cortical dopamine pathways underlying control perception is discussed.

Keywords: Control; Locus of control; Personality; Self regulation; Emotion; Executive functions; Social cognition; Prefrontal cortex; Dopamine

1. Introduction

Understanding the perception and attribution of control has long been a major objective in psychology research, receiving much attention in diverse fields such as clinical psychology, cognitive neurosciences, child development, and the study of personality. Feeling in control is, along with our abstract intelligence and sociality, arguably one of our most human capacities, and forms an essential ingredient in a description of normal (or healthy) personality. Many psychological inflictions, ranging from depression or learned helplessness to addiction and psychoticism are inevitably accompanied by a sense of loss of control. In contrast, a description of "healthy" personality is bound to include a repertoire of social and cognitive skills which allow self-regulation of behaviour in such a way that the person perceives to be, and also acts, in control. The behaviours which make such control possible have often been attributed to a number of personality traits on the one hand, or to neurological underpinnings on the other hand. But too often, these two approaches to the study of complex behaviours (such as feeling in control) are studied independently. To fully understand the integrated behaviours of a normally functioning person, it is essential to think in multifaceted ways. Neither the chemistry of brain function, nor a set of personality traits, can explain exactly why a person is prone to become depressed or loose control. In line with the approaches taken in the social-cognitive neurosciences (Klein, Rozendal, & Cosmides, 2002; Ochsner & Lieberman, 2001), this review therefore aims to bridge several levels of analyses to arrive at a combination of traits and underlying brain functions which are necessary for a person to have a healthy personality and gain control over the environment.

Styles and measures of perceived control have been assessed in various ways throughout the history of psychology, and have been typified as "locus of control," "illusion of control," "personal causation," "personal control," "personal agency," "psychological reactance," "intrinsic motivation," "self-efficacy," "attributional style," and "control motivation" (Wegner, 2002). Addressing all of them would

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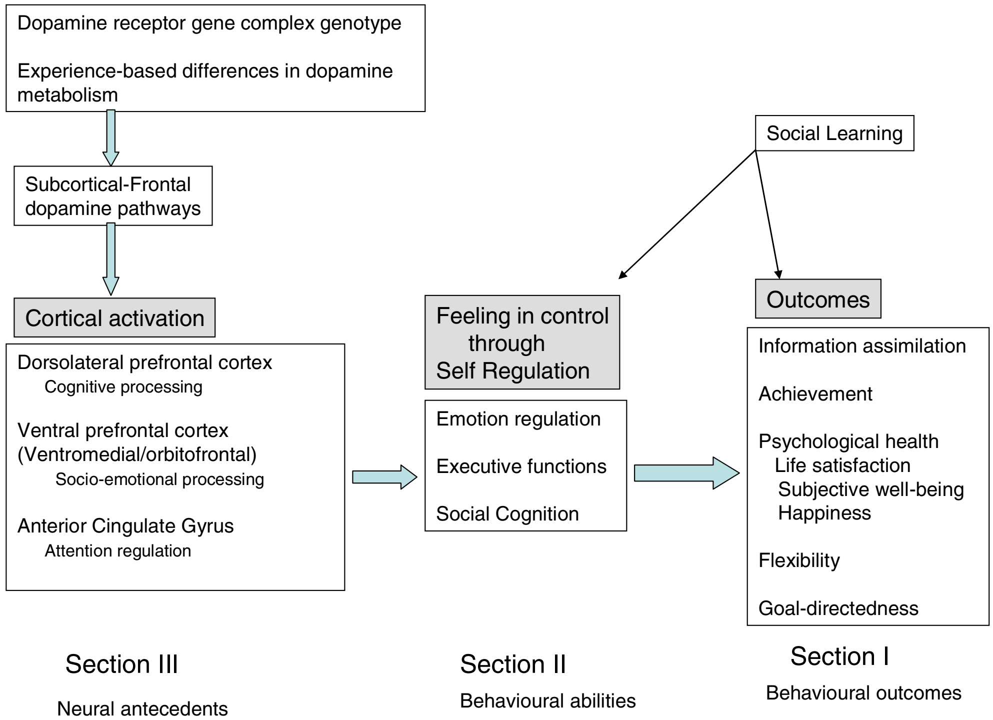


Fig. 1. Model of a possible scenario accounting for differences in internal versus external locus of control orientations.

be an impossible task. Therefore, the focus of this review will be on the locus of control (Rotter, 1966), a particular personality trait which measures the extent to which a person attributes control over the outcome of environmental events to one-self. Because this trait has been studied extensively through self-report questionnaires, and found to have much predictive value with respect to psychological health and successful behavior, we will treat the locus of control as a kind of proxyvariable for perceiving control.[1] The goal of our study is to show that the traditional view of locus of control as a trait which develops through social learning is incomplete. This review proposes that, in addition to social learning, a number of biological processes are also crucial for the ability to assume control over the outcome of an event. To illustrate this, we will develop a testable biological model which depicts some of the neural correlates and behavioral propensities of feeling in control. This model is shown in Fig. 1, and serves as framework for the organization of this review.

Thus, this review is organized as follows: First, we will briefly review what are considered to be some of the traditional antecedents and behavioral outcomes of the locus of control (labeled I in Fig. 1). At the same time, we will also position the locus of control relative to other personality traits which appraise various forms of control. Next, we propose the hypothesis that the locus of control (as well as control perception in general), is a product of the brain's self-regulatory capacities which are responsible for turning environmental sensations into individual actions. These self-regulatory capacities can be studied on a behavioral or on a neural level. On a behavioral level (labeled II in Fig. 1), we will examine how control perception correlates to a number of emotional, cognitive, and social skills which allow a person to self-regulate behavior in a changing environment. In Fig. 1, these abilities are labeled as emotion regulation, executive functions, and social cognition respectively. Their relation to the locus of control in particular will be discussed in detail. Finally, on a neural level (labeled III in Fig. 1), we will present some of the indirect evidence for the neuro-anatomical and neurochemical correlates of these abilities which we believe are necessary (but not necessarily sufficient) for control perception and consequently, for feeling in control.

2. Locus of control: antecedents and behavioural outcomes

The locus of control is a personality trait which refers to the source of perceived control a person has developed; the essence of this trait rests on the assumption that people vary consistently in their individual social learning experiences, giving rise to further differences in the degree to which they are generally able to associate a reward or reinforcement with their own preceding behaviour (Rotter, 1966). A person is said to have an internal locus of control if he or she generally believes that a reinforcing event is

[1] A note on the terminology: while the terms "feeling in control" and "control perception" are used interchangeably throughout this paper, control perception refers specifically to a human skill, while feeling in control is the subjective feeling which emerges directly as a result of this skill. The term "locus of control" is used when we refer to the quantifiable personality trait which reflects individual differences in control perception.

contingent upon his or her own behaviour. At the other end of the continuum, a person is said to have an external locus of control if he or she does not perceive any contingency between a reinforcing event and personal action, but instead attributes the event to luck, chance, fate, or powerful others, or simply labels the event as unpredictable. Most people, naturally, fall somewhere in between this spectrum from internal to external, and therefore, the locus of control is best measured on a scale.

In Rotter's social learning theory (1954) an individual's behaviour in a given situation is influenced by the anticipation, or expectancy, that the behaviour in question will lead to reinforcement. This expectancy is the result of an association with a prior experience in a situation which is perceived to be similar. A generalized expectancy of reinforcement will develop as a function of the reinforcement history in similarly perceived situations. When the reinforcements are mostly perceived as contingent on the individual's behaviour, a generalized expectancy of internal control will develop. However, repetitive failure of reinforcement, or repeated experience with powerful others or uncontrollable forces can influence individuals to develop an external orientation. Therefore Rotter suggested that the consistency of discipline and treatment by parents is a worthy study of possible antecedents of locus of control orientations. Indeed, the antecedents of individual differences in locus of control in children have mostly been studied from a social learning perspective (e.g., Carton & Nowicki, 1994; Carton, Nowicki, & Balser, 1996), or from attachment theory (e.g., Fonagy, Redfern, & Charman, 1997; Houtmeyers, 2002; Volling, 2001). For example, Carton and Nowicki (1994) concluded from a literature review that consistent parental discipline and reward tended to be associated with the development of internal control expectancies in children, while stressful events and authoritative parents seemed more associated with generalized external control expectancies. Furthermore, internally oriented children tend to have parents who grant them more autonomy and trained them to be independent at an earlier age (Carton & Nowicki, 1994; Lynch, Hurford, & Cole, 2002). But the role of parenting in the early childhood years in determining the development of a child's generalized control expectancy, is incomplete, as it ignores the fact that children vary tremendously in temperament, and that the child, by nature of its temperament, may also elicit a certain treatment by a parent (Thomas & Chess, 1977).

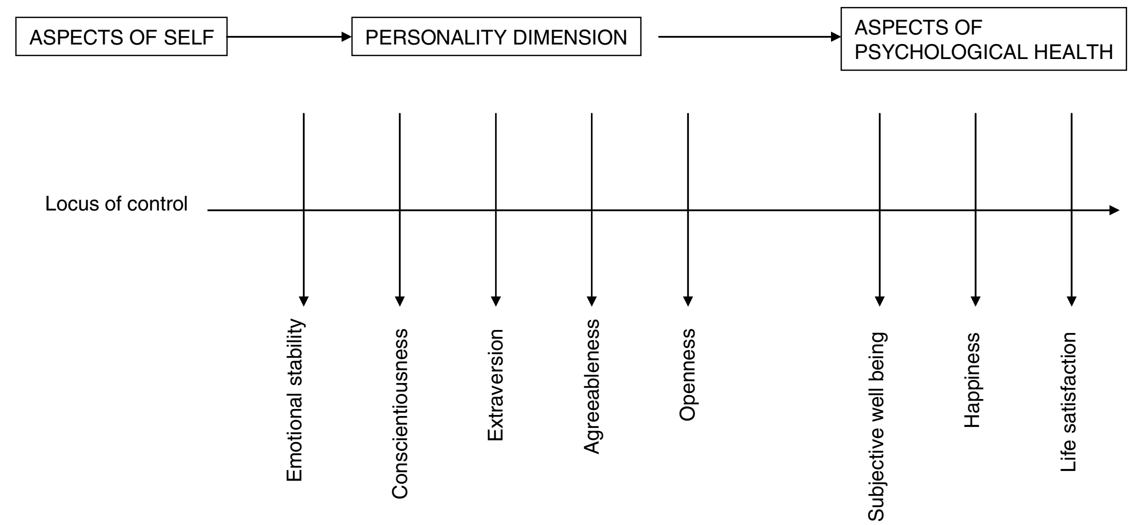
Rotter further suggested that, in addition to social learning, the ability to recognize causality is also likely to be a fundamental basis of locus of control:

> "However individual differences in how causality is assumed to relate events has not been a subject of investigation. It would seem that some relationship would exist between how the individual views the world from the point of view of internal versus external control of reinforcement and his other modes of perception of causal relationships" (Rotter, 1966, p. 4).

Up until today, this issue still has received little attention, and neither has it been subjected to abundant experimental investigation. These "modes of perception" giving an individual the capacity to establish contingencies between events rely on a nervous system which turns sensation into perception. Therefore they encompass inborn capacities which are directly influenced by brain activity. Ultimately it is through subtle and perhaps innate differences in these modes of perception that individual differences will arise in how people learn about the world and feel, act, or adapt, accordingly.

There are already indications that, in addition to social learning, there may be a biological component to the locus of control. First, the psychophysiological correlates have been reviewed by Blankstein (1982). From his review, it appears that internals tend to have (slightly) superior self-control skills which may allow them to better maintain a homeostatic internal environment. Externals, in contrast, are found to show greater arousal levels (measured by physiological indicators such as heart rate and skin conductance), are less able to habituate to irrelevant noise, and are less able to control EMG activity by bio-feedback exercises. Second, quantitative genetic studies have indicated that the locus of control orientation tends to be partly inherited (Miller & Rose, 1982; Pederson, Gatz, Plomin, Nesselroade, & McClearn, 1989). Third, studies by De Brabander et al. show that the locus of control is also related to fundamental attentional regulation processes (De Brabander, Boone, & Gerits, 1989, 1992; De Brabander, Gerits, & Boone, 1990a, 1990b). And finally, individual differences in locus of control may be related to dopamine metabolism (De Brabander & Declerck, 2004). We will return to the latter two issues in more detail later. First, we want to specify why individual differences in locus of control are likely a consequence of differences in social learning due to, or interacting with, the biological mechanisms which turn perceptions into subsequent action. Our approach should not, however, be interpreted as a pure reductionist (i.e., genetic) explanation of individual differences. Although genetics are undoubtedly important in understanding personality differences (Bouchard, 1994; Plomin, Owen, & McGuffin, 1994), biological mechanisms refer in the first place to brain functions and underlying neurochemical processes. These may themselves be either innate reflections of an individual's genetic constitution, or environmentally determined, or the outcome of the interaction of both.

Social learning and the biology of perception are both broad phenomena. Therefore, we expect that the locus of control (as we will treat it in this review), is not a narrow concept which exclusively describes one specific trait. More generally, we believe that "feeling in control" represents a blend of socially desirable traits that are all related to psychological well-being and successful performance. In other words, within the space of the major dimensions of personality, locus of control is located "between" factors, being a mixture of roughly independent dimensions (Fig. 2a). If so, it is expected that the locus of control would be a better a



b

		Locus of control	Emotional stability	Conscien-tiousness	Extra-version	Openness	Agreeable-ness
ASPECTS OF SELF	Self Efficacy	(.56)[2]					
ASPECTS OF SELF	Self esteem	(.52)[2]					
ASPECTS OF SELF / BIG 5 PERSONALITY DIMMENSIONS	Emotional stability	(.52)[1] (.40)[2] (.51)[3]					
BIG 5 PERSONALITY DIMMENSIONS	Conscien-tiousness	(.37)[1] (.31)[2] (.47)[3]					
BIG 5 PERSONALITY DIMMENSIONS	Extraversion	(.40)[1] (.26)[2] (.36)[3]					
BIG 5 PERSONALITY DIMMENSIONS	Agreeable-ness	(.17)[1] (.19)[2] (.16)[3]					
BIG 5 PERSONALITY DIMMENSIONS	Openness	(.00)[1] (.24)[2] (.03)[3]					
ASPECTS OF PSYCHOLOGICAL HEALTH	Subjective well-being	(.42)[1] (.34)[4]	(.22)[4]	(.21)[4]	(.17)[4]	(.11)[4]	(.17)[4]
ASPECTS OF PSYCHOLOGICAL HEALTH	Happiness	(.52)[2]	(.25)[4]	(.16)[4]	(.27)[4]	(.06)[4]	(.19)[4]
ASPECTS OF PSYCHOLOGICAL HEALTH	Life satisfaction	(.17)[2]	(.24)[4]	(.22)[4]	(.17)[4]	(.14)[4]	(.16)[4]

Fig. 2. (a) Positioning of locus of control as the cross section of various personality dimensions and aspects of psychological health (see (b) for correlation coefficients). (b) Correlation coefficients relating the locus of control, to other aspects of self, Big 5 personality dimensions, and aspects of psychological health. (1, Morrison, 1997; 2, Judge et al., 2002; 3, Judge et al., 2004, 4, DeNeve and Cooper, 1998).

predictor of a person's subjective well-being and achievement potential compared to each of the separate dimensions by themselves. This is substantiated by literature findings, as shown in Fig. 2b. In positioning the locus of control in the space of personality, we have focused on the dimensions of the BIG 5, because many lines of reasoning and many longitudinal and cross-cultural studies have shown these five factors to represent basic dimensions of personality (Costa & McCrae, 1992; Rossier, Dahourou, & McCrae, 2005). Furthermore, it has recently been suggested that they represent a set of building blocks providing basic information about superordinate personality which delineate normal versus abnormal psychology (Markon, Krueger, & Watson, 2005). Fig. 2b shows that the locus of control is consistently significantly correlated with conscientiousness (see also Ackerman & Heggestad, 1997;

DeNeve & Cooper, 1998), emotional stability (the converse of neuroticism) and, to a lesser extent, extraversion.[2] A study by Hattrup, O'Connell, and Labrador (2005) indicates that the locus of control has incremental validity after controlling for conscientiousness in its relation with work performance. Fig. 2b also shows that, when it comes to the correlations between locus of control and aspects of psychological health, the locus control is a stronger predictor of subjective well-being and happiness than either conscientiousness, emotional stability, or extraversion alone.

The locus of control is clearly not the only blend of personality measures which predicts well-being and success. Based on their meta-analytical results of four studies, Judge, Erez, Bono, and Thoresen (2002) have recently proposed that locus of control, self esteem, emotional stability, and generalized self-efficacy are all markers of a higher order concept expressing "self aspect," Judge et al. suggest this is based on the poor discriminant validity and high correlations of these 4 measures.[3] Indeed, at least conceptually, these four traits share many similarities as they all assess the positivity of self description (Judge, Van Viaenen, & De Pater, 2004). While Judge et al.'s review is convincing in portraying the locus of control as a subset of a higher order construct expressing a person's "self concept" (see also Erez & Judge, 2001), a systematic examination of the correlations between the individual self-aspect measures (including the locus of control) and the Big 5 traits also shows significant differences. Each of these self aspect measures is likely to represent its own "blend" of Big 5 traits, differing in their predictive values with respect to various aspects of well-being. Taken together, they would represent a composite with even greater predictive value. However, the position of the locus of control within the "self aspect" construct is not unchallenged, as it repeatedly appears that the locus of control displays smaller correlations with the composite "self aspect" factor as do the other three dimensions (Bono & Judge, 2003). Furthermore, the locus of control is much less, or not at all, correlated with agreeableness and openness (Fig. 2b). The latter factor is most closely related to psychometric intelligence (Costa & McCrae, 1992). Consistent with this, the locus of control does not appear to correlate with either fluid- or crystallized-intelligence (Ferguson, 1999). The high achievement potential in academic settings (both in children and adults) which is often associated with an internal locus of control is therefore probably more likely due to the high correlations with conscientiousness, and has little to do with innate intelligent abilities or intellectual engagements. We believe that, for the purpose of this review, considering the locus of control as a well demarcated entity of perceived control is warranted based on its distance from other measures of self aspect, and based on its position between the BIG 5 dimensions of conscientiousness, emotional stability, and extraversion, with the near absence of relationships with either agreeableness, openness, or measures of innate or generalized intelligence.

A more pragmatic advantage of focusing on the locus of control in this review is the continuing enormous interest that the psychological community has in understanding the antecedents and consequences of this trait. Judge et al. (2002) report that the locus of control is one of the most widely studied traits, appearing as key word in 13,428 articles cited in the PsycINFO database since 1887. In addition, focusing on a specific, yet general, trait allows us to be more coherent and precise when articulating the links of our model.

In summary, the locus of control might be conceived of as representing the cross section cutting across several parallel-running traits which contribute independently to a person's capacity to feel in control and subsequent psychological well-being and performance potential. But instead of focusing on the relation between locus of control and other personality dimensions, our review is novel in that it addresses the relation of the locus of control with underlying emotional and socio-cognitive abilities, which are ultimately linked to any of the biological or learned differences in personality (Ackerman & Heggestad, 1997). Thus, for the purpose of our review, we will approach the locus of control as one of the possible phenotypic expression of a number of underlying behavioural and biological building blocks, having a potentially pervasive impact on other aspects of human personality. This concept forms the basis of the model we develop in this review.

Some of the well-researched and more specific behavioural outcomes of a particular locus of control orientation are depicted in Section 1 of the model in Fig. 1. Studies on the locus of control have so far shown that this concept tends to have much predictive value across many situations. In the cognitive domain, Lefcourt (1982) has summarized an extensive body of research showing that individuals with an internal locus of control are superior in assimilating information and tend to be greater achievers. With respect to the latter, individual differences in locus of control have also been reported for school achievements (e.g., Findley & Cooper, 1983; Landine & Stewart, 1998; Nowicki & Strickland, 1973; Skinner, Wellbourn, & Connel, 1990; Stipek, 1980), and leadership abilities or career success (e.g., Andrisani & Nestel, 1986; Boone, 1992; Bradley, Nicol, Charbonneau, & Meyer, 2002; Cummins, 1989; De Brabander, Boone, & Van Witteloostuijn, 2000; Hansemark, 2003; Hattrup et al., 2005; Lefcourt, 1982; Miller & Toulouse, 1986; Popper, Amit, Gal, Mishkal-Sinai, & Lisak, 2004; Van Olffen, 1999). In other domains, individual

[2] A study by Abe (2005), reports correlations between locus of control and the BIG 5 measures for children. The high correlations with conscientiousness is still apparent, but the correlations with extraversion and emotional stability are lower.

[3] Based on 127 correlations among personality measures, Judge et al. (2002) reported that for the combined relations between locus of control, neuroticism, self-esteem, and generalized self-efficacy, the average population correlation was found to be .60, which is substantially higher than the correlations among most personality traits.

differences are especially noted in health and psychological well-being,[4] job satisfaction and happiness (e.g., Breckenridge & Dodd, 1991; Burger, 1984; Declerck, De Brabander, Boone, & Gerits, 2002; Gerits, 1997; Kirkcaldy, Shephard, & Funham, 2002; Kobasa, Maddi, & Kahn, 1982; Parkes, 1984).What almost all these behavioural outcomes have in common (information assimilation, achievement, leadership, and well-being) is that they are indicative of flexible, goal-directed behaviour (Van Olffen, 1999; Lefcourt, 1972).

Goal-directedness and flexibility in behaviour epitomize the evolutionary trend towards increased behavioural plasticity in primates. This plasticity is made possible by the built-in flexibility of a nervous system which learns from experience, allowing animals to adjust their behaviour rapidly to certain environmental conditions, but at the risk of erroneously responding to other events. Thus, human behaviour moved away from a pure stimulus-response mechanism (determined by a hard-wired brain) in favour of self-regulated behaviour accomplished through interplay of specific neural networks which develop, or may be modified, in response to environmental experiences (Karmiloff-Smith, 1998; Mesulam, 1998).

In the next section, we will further examine the idea that control perception is an intermediary between the human ability to self-regulate emotions and behaviour, and the ultimate flexible and goal-directed behaviours that follow.

3. Locus of control and behavioural self regulation

Self regulation refers to the brain's capacity to escape pre-determined, hard-wired responses to environmental stimuli in a flexible yet systematic way. On a neural level, the synaptic networks which link sensation of stimuli to cognition and subsequent action have been nicely described by Mesulam (1998). He draws attention to the essential role of the prefrontal cortex, which allows neural responses to reflect the significance, rather than the "surface properties," of sensory events. Mesulam further describes how the prefrontal cortex is essential for flexible behaviour because it inhibits the habitual responses that have become inappropriate. One of the prefrontal functions that makes this possible is working memory.[5] It prolongs the impact of sensory experiences by allowing multiple representations of stimulus-response options to be held in consciousness. Through working memory and the synaptic events in the prefrontal cortex, representations of external events (sensations) and internal phenomena (perceiving causal relationships) can unfold concurrently and interactively without distraction from other stimuli, so that new combinations of behavioural responses can be mentally evaluated before an actual response is carried out (Mesulam, 1998). This increased flexibility in responding must rely on a mechanism to select certain responses over others in a self-regulatory fashion, i.e., in a way which directs human behaviour towards the possibility to perceive and manipulate causes, and away from purely reflexive perception-action. This response selection system in the linkage from sensation to cognition forms the essence of the self-regulation of behaviour. We hypothesize in this paper that these functions which make self-regulation possible, also make one feel in control. To assume control over the outcome of an event presupposes that one has the ability to look ahead, and to select one specific behaviour out of a set of possible behaviours because it is more appropriate in achieving the desired outcome compared to other behaviours.

In the next section of this paper, we will discuss three aspects of self regulation which we believe to be necessary (but not necessarily sufficient) components with respect to developing a feeling of being in control, or, more specifically, an internal locus of control. These are: (1) emotion regulation, (2) executive functions, and (3) social cognition. Emotion regulation includes approach (and withdrawal) motivation and develops in childhood in part as a consequence of orienting attention according to the emotional content of the current incoming information. Executive functions and social cognition are both aspects of behavioural regulation which require higher level cognition; they allow a future-oriented view of the world, and hence make the behaviours described at the beginning of this section, information assimilation, goal-directedness and flexibility, possible.

For each of these brain functions, we will first define what they are and state why we believe it to be part of a process which leads to a feeling of control. To this effect, we summarize studies which point to a link with locus of control. Next, we address more specifically the functional role of three cortical areas (see Fig. 1). Finally, we discuss some of the innervating neurochemical pathways.

3.1. Emotion regulation and motivation

In his discourse on the origin of "conscious will," Wegner (2002) argues that "feeling in control" is essentially an emotion, and that "emotion regulation" assigns authorship to the thoughts and feelings we have and the actions we perform. For Damasio (2003), motivation is an additional component nested in the emotion-regulatory mechanism from which feelings and actions emerge. In describing the functions of emotions, Rolls (2000a) argues that emotion regulation is closely tied to the flexibility of behavioural responses. The essence of his ideas is that emotions, being at the interface of sensory inputs and actions, are those states which are elicited by rewards and punishments. Goals for behaviour are thus specified by the motivation to obtain reward and avoid punishment. Consistent with Rotter's social learning theory, feeling in control of one's goal-directed and persistent efforts is

[4] High correlations between happiness and a positive self aspect and locus of control are reported in Fig. 2.

[5] Working memory refers here to the on-line integration of multiple domains of neural activity without the need to transfer them into and out of long term-storage (Mesulam, 1998).

likewise only possible when emotions are regulated effectively in such a way that the act of goal achievement is consistently reinforced while one is not swept away by negative events which may have been incurred in the process. When this happens systematically, a feeling of control over a situation may emerge over time as one learns to associate motivated, or approach behaviour with reward, and withdrawal behaviour with punishment. Thus, an emotion regulation system functions to select those behaviours which will lead to rewards, and avoid those behaviours which will lead to failure. Without this system, there can be no feeling of control, and goal-directed behaviours would not be possible.

As emotions tend to last long after the reinforcing stimulus has occurred, persistent and continuing motivation for goal-directed behaviour results. In addition, the current mood (positive or negative emotion) may affect the cognitive evaluation of events or memories (Oatley & Jenkins, 1996), thereby facilitating the continuity in the interpretation of the reinforcing value of the events. This in turn influences the generalized expectancy pattern which people are developing with respect to the outcome of future events. In this way emotion regulation also contributes to the development of a durable and stable locus of control. The extent to which control of a situation can be perceived would then depend on its long-term association with affective stimuli which have elicited either reward or punishment in similar situations.

Therefore we expect that internally oriented people will be more motivated to obtain rewards and more sensitive to avoid punishment. As an illustration of this tendency, Lefcourt (1972) describes how internally oriented individuals attend indeed more to rewards and successes, while externally oriented individuals attend to punishment and failures. We also expect at the same time that internals are able to deal more effectively with the consequences of failures. They should be less likely to experience negative affect due to punishment. When facing stressful events, internals are expected to be able to generate more hopeful situations via coping mechanisms which focus on positive solutions.

In childhood, temperamental differences in such approach/withdrawal behaviours are known to influence emotional states and consequent control perception later in life (Chorpita & Barlow, 1998; Dweck & Leggett, 1988). Chorpita and Barlow (1998) have described a mechanism accounting for how low perceived control and helplessness may result from the incapacity to withdraw from negative affective events in early childhood. In infants, before environmental input can be interpreted or moderated with cognition or memory, emotion regulation is essentially a job of regulating attention away from aversive and towards comforting stimuli and is believed to be a stable temperamental trait (Derryberry & Rothbart, 1997; Kochanska, Murray, & Harlan, 2000; Posner & Rothbart, 2000; Rothbart, Ahadi, & Evans, 2000; Rothbart, Derryberry, & Posner, 1994; Rothbart, Ellis, Rueda, & Posner, 2003).

3.1.1. Correlations between emotion regulation and locus of control

If an emotion regulation mechanism specifying goals to obtain reward and avoid punishment (Rolls, 2000a) also generates a feeling of control, then we would expect individual differences in control perception to correspond to differences in behaviours that are necessary to achieve these goals. Specifically, we expect that internal control perception correlates positively with appetitive, or motivated behaviour, and negative with states of negative affect. The latter would be the result of enhanced effectiveness of avoiding negative emotions. In other words, in a situation involving reward, an individual with internal control perception should be more motivated. In a situation involving punishment, an individual with internal control perception should cope more constructively to avoid the negative effects of the punishment.

With respect to motivated behaviour, many studies have indicated that individuals with an internal locus of control are more motivated in rewarding situations and that they will also seek out rewarding situations more often compared to externally oriented people (Feather & Volkmer, 1988; Holmes & Jackson, 1975; Howell & Gregory, 1980; Taub & Dollinger, 1975). Furthermore, internally oriented individuals also use evaluative feedback more in order to gain additional control over a reward-contingent condition (Quaglieri, 1980; Trusty & Macan, 1995).

With respect to affective behaviour, control perception has often been implicated as a key determinant of individual differences. Healthy, or positive, emotionality is often attributed to controlling one's environment effectively under stress, while persistent negative emotions tend to go along with uncontrollability (Chorpita & Barlow, 1998; Folkman, Lazarus, Gruen, & DeLongis, 1986; Posner & Rothbart, 2000). Many animal models have also shown that lack of control leads to helplessness (Minor, Dess, & Overmier, 1991; Seligman & Maier, 1967). In people as well, feelings of helplessness or loss of control are often accompanied by feelings of anxiety and/or depression (Declerck et al., 2002). People with an external locus of control also tend to be more reactive to negative events and express more negative affect (Boone, De Brabander, Gerits, & Willemé, 1990; Burger, 1984; Clarke, 2004; Glazer, Stetz, & Izso, 2004; Hahn, 2000; Hale & Cochran, 1987; Parkes, 1984). In contrast, people with an internal locus of control report having more control over the source of the stressor, and they show reduced levels of salivary cortisol (Bollini, Walker, Hamann, & Kestler, 2004). In children, an external locus of control measured by the Nowicki–Strickland Locus of Control Scale has been shown to correlate with anxiety scores (Finch & Nelson, 1974; Nunn, 1988) and with depression (McCauley, Mitchell, Burke, & Moss, 1998). Lefcourt (1982) has also reviewed many studies on anxiety and locus of control, pointing to the fact that their relation is consistently and statistically significant. Considering the large incidence of psychopathology associated with helplessness and an external locus of control, Lefcourt (1982) believes that external locus of control orientation is predictive of emotional personal functioning.

One way to regulate emotions and to overcome the debilitating effects of stress and subsequent anxiety is through the development of coping mechanisms. Differences in coping styles, such as the degree of defensiveness, repression, or intellectualization, are known to differ for internal and external control-oriented individuals (Lefcourt, 1982; Masters & Wallston, 2005). There is also direct experimental evidence to believe that the cognitive interpretation of the emotional state is related to a person's perceived control in a stressful situation. During a simulated captivity (Strentz & Auerbach, 1988), individuals with an internal locus of control who were held hostage tended to rely on problem-focused coping strategies (i.e., short-circuiting negative emotions through acting and believing that the stressors can or will be controlled instrumentally). Individuals with an external locus of control in the same hostage situation tended to rely primarily on emotion-focused coping. This included tactics like relaxation techniques to diminish the dysphoric emotions elicited by the stressors, but no active stance towards eradicating them.

In addition to the experiment described above, significant correlations between emotion-focused coping styles and an external locus of control has been reported for women during normal-risk pregnancy (Huizink, de Medina, Mulder, Visser, & Buitelaar, 2002), job applicants in assessment centres (Hess & Vossel, 2001), carers of home dialysis patients (Piira, Chow, & Suranyi, 2002), cancer patients (Ma, 1997), pseudoseizure patients (Goldstein, Drew, Mellers, Mitchell-O'Malley, & Oakley, 2000), relatives of schizophrenia patients (Bentsen et al., 1997) and in a group of 173 normally functioning community-dwelling men and women (Horner, 1996). In contrast, problem-focused coping was related to an internal locus of control and fewer stress symptoms in a group of high school teachers (Olff, Brosschot, & Godaert, 1993). An internal locus of control was also found to correlate with positive changes in cognitive and socio-emotional functioning in a group of high-risk children between the ages of 4 and 13 (Seifer, Sameroff, Baldwin, & Baldwin, 1992). Such findings indicate that the way in which a person relies on cognition to control emotions in stressful situations is likely to be an integral element of the locus of control.

Although we know of no longitudinal studies which have examined the relation between temperament and developing locus of control directly, it is possible to formulate some testable predictions based on the theory we have so far presented. Recurring stressful situations could either lead to anxiety and an external locus of control if emotion regulation is weak, or to an internal locus of control inoculating individuals against the negative effects of stress when emotion regulation is high. Additional research could test the validity of these predictions.

To summarize the role of emotion regulation in developing control perception, we have suggested that feeling in control results from (1) motivated behaviour associated with rewarding situations, (2) problem- focused coping mechanisms in stressful situations, and (3) the temperamental ability to switch attention, or the propensity to resolve conflicts by selecting to respond only to those stimuli which will lead to reward, and inhibit responding to inappropriate or negative stimuli. Assuming that emotion regulation serves an individual in gaining the highest net reward from the environmental inputs (Rolls, 2000a), it would need to be integrated with other cognitive functions which aid in future-oriented behaviour. In other words, emotion regulation needs to be closely tied to the functions leading to intentional or goal-directed thinking (Eisenberg & Spinrad, 2004; Frye, 1999). These functions form the essence of the mind's behavioural self-regulation, a topic to which we turn next.

3.2. Executive functions

Higher level cognitive functions which are mediated by the human prefrontal cortex and are involved in the control and direction of lower level functions, have been called collectively the "executive" or "frontal executive" functions. (Reviews on theory and research regarding the frontal executive functions can be found in Barkley, 2001; Hughes, 1998a, 1998b; Miyake, 2000; Perner & Lang, 1999; Stuss & Levine, 2002). Executive functions can be regarded on the one hand as abilities, referring to those cognitive capacities such as inhibitory control, working memory, planning, and strategic thinking. All these abilities make behavioural self-regulation possible. On the other hand, some authors view the executive functions more as the psychological processes involved in flexible and goal-directed problem-solving (Zelazo, Muller, Frye, & Marcovitch, 2003). Both views are compatible with our hypothesis that the executive functions are an essential component of perceiving control (Fig. 1), or the feeling of control which goes along with intentional thinking (Wegner, 2002). Perceiving control would result, at least in part, from being aware of those functions one has available to plan or to delay responding to a situation in order to achieve a desired goal. Because more frontal cortical involvement is required as executive functions become more complex (Stuss & Levine, 2002), increased cognitive control over subjective experiences is expected to develop ontogenetically according to the rule-based reasoning capacities which develop with the maturation of the frontal cortex. Developmental studies assessing the reasoning capacities, executive functions, and cognitive control in infants and young children are confirming this (Zelazo, 1999; Zelazo et al., 2003).

Among the frontal executive functions, two categories can be distinguished. Those skills which are purely cognitive and require abstract thinking skills, such as working memory, strategic thinking, and planning, tend to rely primarily on the dorsolateral prefrontal cortex. Tasks which in addition to cognition require some emotional or social processing, such as delaying gratification or impulse control, seem to rely more on the ventromedial and the orbitofrontal prefrontal cortex (Rolls, 2000b; Stuss & Levine, 2002). Episodic memory, or the ability to develop a self concept based on personal memories, is made possible in part by the contribution of the most anterior portion of the prefrontal cortex (frontal poles or Brodmann area 10). Any executive function task which requires attention switching, conflict resolution, or response selection, will also activate the anterior cingulate gyrus (Corbetta, Miezin, Shulman, & Petersen, 1993; Devinsky, Morrell, & Vogt, 1995; Hunter et al., 2003; Mundy, 2003; Tekin & Cummings, 2002). We return to the significance of these structures with respect to feeling in control later in the paper.

3.2.1. Correlations between locus of control and frontal executive functions

If control perception is indeed dependent upon the intact functions of the above mentioned areas of the prefrontal cortex, it should follow that lesions in these areas, or deficits in frontal executive functions, are associated with a reduced ability to perceive control, or at least with a more pronounced external locus of control. Conversely, superior executive functioning would be expected to correlate with a more internal locus of control. Although we are not aware of any theoretical paper which has addressed the relation between locus of control and frontal executive functions in general, many empirical research articles have attempted to correlate locus of control with one or more particular frontal cortex function. We will next address a number of studies which have established such a link. They are also summarized in Table 1.

3.2.1.1. Locus of control is affected by deficits in frontal executive functions. A first hint we get for a relation between locus of control and frontal cortex executive functioning is from psychopathological assessments. An external locus of control has repeatedly been found to be overrepresented in children and adolescents who suffer from attention deficit hyperactivity disorder (ADHD) (Lufi & Parishplass, 1995; Purvis, 2000; Rucklidge & Tannock, 2001), a condition which is marked by poor impulse control and a clear deficit in executive functions (Barkley, 1997; Nigg, 2000). Similarly, there are reports that schizophrenia seems to be accompanied by a change towards a more external locus of control (Pinto, Grapentine, Francis, & Picariello, 1996; Watson, 1998), or sometimes even an extreme external locus of control (Chadwick, 2001). These findings are relevant when we consider that there are numerous experimental findings showing that schizophrenia is associated with abnormal frontal lobe functioning (Baare et al., 1999; Carter, MacDonald, Ross, & Stenger, 2001; Gold, Goldberg, & Weinberger, 1992; Siedman et al., 1994; Tekin & Cummings, 2002; Weinberger et al., 2001), as well as impaired executive functioning (Chey, Lee, Kim, Kwon, & Shin, 2002; Heinrichs & Zackzanis, 1998; Morice & Delahunty, 1996; Pantelis et al., 1999; Vahurin, Velligan, & Miller, 1998).

Studies relating brain lesions in cortical areas to changes in locus of control orientations are, naturally, hard to come by, because rarely are personality measures available from a time before the occurrence of the lesion. However, in one study of 74 brain-injured patients, both pre and post injury personalities were obtained. The locus of control of the

Table 1
Summary of studies presenting empirical or experimental evidence for a relation between locus of control orientations and frontal executive functions

Psychopathology	*ADHD*	Lufi and Parishplass, 1995; Rucklidge and Tannock, 2001; Purvis, 2000
	Schizophrenia	Chadwick, 2001; Pinto et al., 1996; Watson, 1998
	Brain lesions	Lubusko et al., 1994; Malia et al., 1995
Strategy and planning	*Planning tasks*	Das et al., 1995; Gardner and Helmes, 1999
	Study skills	Onwuegbuzie and Daley, 1998; Fazey and Fazey, 2001; Garden et al., 2004
	Problem-solving	Bethencourt, 1997; Ferguson, 1999; Maine and Rowe, 1993; Wege and Moller, 1995
	Consumer behavior	Busseri et al., 1998; Srinivasan and Tikoo, 1992
	Management	Miller et al., 1982; Welsch and Young, 1982
	Business game	Boone et al., 1991
	Prisoner's dilemma	Boone et al., 1999a, 1999b; Boone et al., 2002
	Time estimation	Koivula, 1996; Shell and Husman, 2001
Impulse control	*Adults*	Brandon and Loftin, 1991; Chak and Leung, 2004; Griffeth and Hom, 1988; Nunn, 1994
	Children and adolescents	Burton and Krantz, 1990; Gelber, 1989; Geller et al., 1981; Innes and Thomas, 1989; Strickla, 1973
	Drinking, smoking and eating behavior	Adolfsson et al., 2005; Collins et al., 2000; Sadava, 1986; Sadava and Thompson, 1986; Schneider and Busch, 1998; Shope et al., 1993; Strom and Barone, 1993; Williams et al., 1987
Memory		Amrheim et al., 1999; Arbuckle et al., 1992; Landau et al., 1993; Riggs et al., 1997; Starnes and Loeb, 1993; Stevens et al., 2001; Verhaeghen et al., 2000
Selective attention		De Brabander et al., 1990a, 1990b ; De Brabander et al., 1990b; De Brabander et al., 1992

patients seemed to be significantly affected between 12 and 30 months after injury, remaining static up till 2.5 years later (Malia, Powell, & Torode, 1995). Moore and Stambrook (1995) developed a conceptual model indicating how long-lasting cognitive effects of traumatic brain injury may create a condition of "learned helplessness," with consequent deficits in coping and altered control beliefs. However, traumatic brain injuries need not be limited to prefrontal lesions, so we can not deduce that diminished control perception would be the result of reduced prefrontal capacities, as opposed to other cortical or subcortical areas, or even post-traumatic stress or socio-economic changes as a result of the injury.[6] The evidence for a relation between locus of control scores and prefrontal functions remains speculative and indirect, suggested especially by differences in performances in the functions subsumed by the prefrontal cortex, as we will show next.

We will next summarize the existing evidence correlating locus of control with the ability to plan and use strategies, control impulses, and rely on memory. How locus of control relates to selective attention (see Table 1) will be discussed in a subsequent section in conjunction with its neurochemistry.

3.2.1.2. Correlations between locus of control and planning ability. If an internal locus of control is associated with superior executive abilities mediated by the frontal cortex, we would expect internals to be better planners and strategists. Indeed, in a study by Das, Naglieri, and Murphy (1995), internally oriented individuals were found to be better at several planning tasks. Students with an internal locus of control also tend to have superior study skills, autonomy, and self-directedness, attributes which undoubtedly reflect planning ability (Fazey & Fazey, 2001; Garden, Bryant, & Moss, 2004; Gardner & Helmes, 1999; Onwuegbuzie & Daley, 1998). In another line of research, Busseri, Lefcourt, and Kerton (1998) report that internality on the Consumer Locus of Control Scale related significantly to consumer behaviour (ranging from strategic to impulsive). The more internal, the more likely participants were planful and purposive in shopping. In yet another study where 1401 car buyers were surveyed, internals were found to engage in a greater degree of information search than externals. Controlling for decision importance, financial risk, and product interest, the locus of control (assessed with a general locus of control scale) was found to influence search behaviour significantly in this sample (Srinivasan & Tikoo, 1992). In addition, other strategic tasks such as effective problem-solving, and abstract means-end thinking have also been related to an internal locus of control in groups of adults (Bethencourt, 1997; Ferguson, 1999; Wege & Moller, 1995), and groups of children (Maine & Rowe, 1993). Finally, internally oriented individuals tend to take an active stance towards problems, while externally oriented individuals tend to view problems as a threat (Lefcourt, 1972).

A crucial aspect of planning is time perspective. Estimating time intervals has been related to impulsivity measures and strategic behaviour (Wingrove & Bond, 1996), as well as to locus of control (Koivula, 1996; Stewart & Moore, 1978). Internals were found to be more accurate in estimating time intervals compared to externals, and this became even more apparent when attention was diverted towards performing mental arithmetic (Koivula, 1996). Similarly, Externals were found to be less accurate in judging time intervals when influenced by external cues (Stewart & Moore, 1978). Another study reports a statistically significant correlation between internal locus of control and future time perspective and studying in college students (Shell & Husman, 2001).

Experimental and field research in a business or entrepreneurial settings has also confirmed the general proposition that internally oriented people engage in more strategic search behaviour and conduct a more extensive information search before making a decision compared to externally oriented individuals (Lefcourt, 1982; Miller, Kets de Vries, & Toulouse, 1982; Welsch & Young, 1982). However, in a simulated investment decision game, Boone, De Brabander, and Gerits (1991) noted that this relation between locus of control and search behaviour did not appear initially, when the task was novel or uncertain. But as time went on in the experiment, the internally oriented participants not only became more persistent in searching for information, they also tended to change their search strategy more often when it was coupled to feedback. This indicated that the internals are capable of using strategies effectively, especially when they are motivated by feedback.

Using strategies may be particularly important in controlling our social environment. To test the hypothesis that internals and externals differ with respect to the use of strategies in a social dilemma, Boone, De Brabander, and Van Witteloostuijn (1999a, 1999b) conducted a series of experiments using the prisoner's dilemma paradigm. From these studies it appeared that internals consistently played more cooperatively than externals, and that they also changed their behaviour in a predictable way (they played competitively only when retaliation was no longer possible). In contrast, the moves made by externals in these same games did not vary from random choices. The total payoff achieved was 60% larger for the internals, adding strength to the belief that the internals used a strategy to obtain a desired outcome. Further experiments by Boone et al. using a prisoner's dilemma paradigm where participants have to adapt to different circumstances over time (i.e., creating a "learning" situation), reveal that internals actually learn to

[6] Tucker (2001) gives a theoretical account for how personality changes accompanying post-traumatic stress could be the result of a kindled limbic response that produces emotional sensitization and alters the neural substrate for memory, thereby disrupting the process of associative learning. This mechanism, relying on limbic deficits as a result of stress, rather than brain lesions, could also account for the changes in locus of control reported by Malia et al., 1995.

cooperate faster than externals, probably because their cognitive style allows them to be quicker learners (Boone et al., 2002).

3.2.1.3. Correlations between locus of control and impulse control. Although theoretical papers on the locus of control have addressed its relation to impulse control (e.g., Crandall & Crandall, 1983), experimental or field studies reporting such correlation are rather scarce. However, direct correlations between impulsiveness and an external locus of control, or between impulse control, the ability to delay gratification, and an internal locus of control, have been documented in children (Burton & Krantz, 1990; Gelber, 1989; Strickla, 1973), adolescents (Innes & Thomas, 1989), and adults (Brandon & Loftin, 1991; Griffeth & Hom, 1988; Nunn, 1994). The locus of control has often been examined in the context of impulse control with respect to alcoholism or abstinence from drinking. Here too, individuals who are more successful in reducing their drinking habits or abstaining tend to have a more internal locus of control (Collins, Koutsky, & Izzo, 2000; Sadava & Thompson, 1986; Shope, Copeland, Maharg, Dielman, & Butchart, 1993; Strom & Barone, 1993). For drinking, as well as for smoking and eating, individuals who report being addicted tend to be significantly more external on general or situation-specific locus of control scales (Geller, Keane, & Scheirer, 1981; Sadava & Thompson, 1986; Schneider & Busch, 1998). A similar relation has been reported for binge eating (Adolfsson, Andersson, Elofsson, Rossner, & Unden, 2005; Williams, Spencer, & Edelman, 1987). Recently, Internet addiction has also been associated with an external locus of control (Chak & Leung, 2004).

In an experimental setting, preliminary evidence suggests that internals may show better impulse control during a go-no go type of task.[7] When the pre-potent response in this task was made more potent due to an external warning cue, externals tended to commit significantly more "go" errors (De Brabander & Declerck, unpublished data), suggesting that they have a more difficult time repressing the urge to respond.

3.2.1.4. Correlations between locus of control and memory. Many of the executive functions place high demands on working memory, and many studies which have looked at the inter-correlations between different executive functions have reported high correlations with working memory capacity (Engle, 2002). Correlations between locus of control and aspects of memory in general vary according to the type of memory task and the age of the participants (Landau, Otani, & Libkuman, 1993). A relation between improved working memory and an internal locus of control has been reported at least once (Riggs, Lachman, & Wingfield, 1997).

Because the locus of control develops as a function of the pattern of generalized expectancies about the outcome of events across many situations, aspects of long-term memory are also expected to be of importance. Indeed, next to working memory, there are several other studies reporting correlations between locus of control and memory. In a sample of 1398 adults ranging in age from 25 to 82 years old, an internal locus of control was one of the significant predictors of memory capacity scores on a delayed recall task of a 15-word list task. (Stevens, Kaplan, Ponds, & Jolles, 2001). Furthermore, an internal locus of control seems to be a better predictor of performance on free-recall memory tests among older, or veteran participants (Amrheim, Bond, & Hamilton, 1999; Arbuckle, Gold, Andres, Schwartzman, & Chaikelson, 1992; Verhaeghen, Geraerts, & Marcoen, 2000). A possible explanation for this age-locus of control interaction effect on memory performance may reside in differences in life style and/or accumulated experiences between internals and externals.

There are, however, alternative explanations for the link between performance on short-term and long term memory tasks and locus of control. The correlations may be spurious and an epiphenomenon of the fact that internals are either more motivated, or that they use more strategies to accomplish their goals. As an indication of the latter, elementary school children who reported that they had used a strategy during a working memory task, and who were able to explain their strategy (as "chunking," or "associating the things to remember with a code") scored significantly more internal on Crandall and Crandall's locus of control scale. Furthermore, these children also performed significantly better on this task compared to the children who reported that they did nothing special to remember (Declerck & De Brabander, unpublished manuscript).

A study by Starnes and Loeb (1993) indicated further that internals and externals did not differ in the total number of words recalled during a recall test, but that they did differ in their use of memory strategies during conditions of quietness and distracting noise. The strategy of internals was unaffected by the presence or absence of distracting noise, while externals changed strategy in conditions with distracting noise: in this case they decreased the semantic memory strategy (remembering a word according to content category), and increased their use of perceptual strategy (remembering a word because it rhymes). Starnes and Loeb interpret this finding by suggesting that internals and externals probably differ with respect to arousal. The idea that externally oriented subjects are also more easily aroused will be discussed further in a later section.

Finally, because the concept of self awareness is integral to feelings, and thus also to feeling in control, we would expect episodic memory to play a crucial role in developing an internal locus of control. This relation has, as far as we know, not yet been investigated. Episodic memory refers to the recollection of autobiographical events. Episodic memory has been found to be neurologically and cognitively dissociated from other memory functions. Neurologically it

[7] The description of this task, as well as details about the experimental procedure, can be found in De Brabander, Declerck, and Boone, 2002.

has been associated with a corticolimbic brain system including the hippocampus, the medial temporal lobe, and the frontal poles (Brodmann's area 10, in the most anterior part of the prefrontal cortex). The hippocampus is essential in the consolidation of memory, with the left hippocampus being more activated when the new memory to be formed is self-relevant (Maguire & Mummery, 1999). Being important in spatial representations, the hippocampus may enable the retrieval of episodic memories by temporally organizing sequences of events and the locations where they occurred (Eichenbaum & Fortin, 2005). The medial temporal poles and the frontal poles of the prefrontal cortex are activated when talking or thinking about future prospects or past experiences, and have been regarded as the substrates for episodic future thinking (Okuda et al., 2003) and mental time travelling (Klein, German, Cosmides, & Gabriel, 2004). Activation in the frontal poles also enables humans to develop a self-concept as they remember past personally relevant experiences, or think of themselves in the future, and integrate this information with other sensory information (Tulving, 2002). Cognitively, it has been argued repeatedly that episodic memory resembles many different neurocognitive functions such as self-referencing, anticipation, and planning (Allman, Hakeem, & Watson, 2002; Kelley et al., 2002; Wheeler & Stuss, 2003). Klein et al. (2004) describe how deficits in episodic memory are accompanied by losses in the capacity for self-reflection, personal agency, and the ability to think about time. Considering the importance of all of these functions to the concept of feeling in control, and the findings reported earlier that individuals with an internal locus of control tend to have superior future time perspectives, it is also probable that they would have better hindsight and episodic memory capacities. Episodic memory empowers humans with the capacity to mentally represent and become aware of subjective experiences in the past, present and future (Wheeler, Stuss, & Tulving, 1997).

3.3. Social cognition

As stated earlier, perceiving control presupposes that one can reason intentionally, or that one is aware that behavioural acts are necessarily linked to certain consequences, a capacity which few or no vertebrates have attained to the level of humans (Barresi & Moore, 1996). Such goal-directed, or intentional thinking is not only an important concept with respect to cognition associated with the executive functions, it is also of equal importance to social cognition. Higher-level cognition is arguably the most characteristic aspects of human behaviour, and it is expressed in abstract as well as in social intelligence. These two types of intelligence may also be intertwined, as much of the evolutionary pressure on the development of abstract intelligence may have occurred from living in group. Indeed, the social brain hypothesis for the evolution of intelligence suggests that the evolutionary pressure for the growth of the human neocortex lies in the need for one brain to communicate with another. It is based on a comparative analysis showing a direct correlation between the size of a species' neocortex and the breadth of the social group in which individuals of that species live (Barrett, Henzi, & Dunbar, 2003; Dunbar, 1998). According to this hypothesis, the selective advantage of intelligence would have been in the first place Machiavellian, serving to gain control over social interactions, rather than to solve physical problems.

We propose that social cognition is also essential in the development of generalized control expectancies, because much of our behaviour, including the perception of control, centres on social issues. People do not usually try to attribute to themselves control over the weather, or natural catastrophes, but they often do try to attain control over social interactions. Social cognition refers to that kind of reasoning which is necessary in order to be able to assess the consequences of one's behaviour in a social context. For example, we are aware that we can easily change our behaviour to elicit a particular response from someone else. To be able to do so requires that we understand people are motivated by a mind similar to our own, as was eloquently described by James nearly a century ago:

> "To me the decisive reason in favour of our minds meeting in some common objects at least is that, unless I make that supposition, I have no motive for assuming that your mind exists at all. Why do I postulate your mind? Because I see your body acting in a certain way. Its gestures, facial movements, words, and conduct generally, are "expressive", so I deem it actuated as my own is, by an inner life like mine. This argument from analogy is my reason, whether an instinctive belief runs before it or not" (James, 1976, p. 38).

What James was describing is the essence of what is known today as a "theory of mind" (TOM) (Premack & Woodruff, 1978), "mind reading" (Whiten, 1991) or "mentalizing" (Frith, Morton, & Leslie, 1991).These terms all refer to the ability to reflect on our own knowledge, beliefs, and desires, and have the additional capacity to imagine, interpret, and react appropriately to the feelings of others, all of which are essential for achieving a common understanding of the environment and for intact social reasoning. Having sparked over a decade of research in child development, we know that theory of mind is not a unitary skill, but that it comprises various abilities which develop gradually as Piagetian milestones at predictable ages (Baron-Cohen, 1999; Flavell, 1999). For example, understanding that someone can hold a false belief is an ability which usually develops around the age of 4 (Wellman, Cross, & Watson, 2001). But already much earlier, around 18 months, an infant can already infer what action another person is trying to perform, even if the person is unsuccessful in the attempt. Hence the child already understands at that age that other people's actions can be intentional and goal-directed (Meltzoff, 1995). Because such intentional reasoning is kin to the ability of establishing contingencies between behaviour and outcome, it is also an essential ingredient in the perception of control over an event, and therefore a necessary part of developing a generalized pattern of control expectancies. It follows that if this capacity for intentional reasoning were reduced or absent, perceived control would also be diminished and the person would likely suffer from an extreme external locus of control. This seems to be true in the case of the mental impairments associated with the psychological conditions of autism and Asperger syndrome (or high-functioning autism). These patients suffer from a reduced capacity for intentional thinking (Hill & Russell, 2002; Phillips, Baron-Cohen, & Rutter, 1998), deficits in theory of mind (Baron-Cohen, 1995; Brune, 2001; Frith & Frith, 1999; Yirmiya, Erel, Shaked, & Solomonica-Levi, 1998) as well as a low capacity for monitoring their own actions (Russell & Jarrold, 1998). Autistic children have a difficult time differentiating between an outcome which is compatible with their own intentions and one with those of others; therefore they can not anticipate how their own actions will affect themselves or other people (Frith & Happé, 1999). These two types of behaviours are also typical of an external locus of control, when the link between behaviour and outcome is not established.

Neurological studies on autism and related disorders have alluded to a network for social cognition which includes a number of cortical and subcortical areas, including the orbitofrontal cortex in the prefrontal region, the superior temporal sulcus, and the amygdala (Brothers & Ring, 1992). Amygdala malfunctions tend to preclude the development of a theory of mind (Baron-Cohen et al., 2000). Furthermore, the amygdala is activated during eye contact, so that its specific role in social cognition may be in reading social signals from the face (Kawashima et al., 1999). In addition, it has been suggested that social cognitive abilities are made possible in part by a "mirror system" located in the left temporal sulcus, containing mirror neurons which fire in response to matching the observation and execution of motor actions (Rizzolatti et al., 1996; Gallese & Goldman, 1998). The idea that theory of mind may have evolved from a brain function which was concerned with the detection of movement (Wolpert, Doya, & Kawato, 2003) is further corroborated by findings that the premotor cortex shows enhanced activity during mind-reading tasks (Frith & Frith, 1999).

3.3.1. Correlations between social cognition and locus of control

If it is the case that social cognition is in a way related to developing generalized control expectancies, we would expect that the same skills which are needed to become socially competent and to function in group are needed to develop an internal locus of control. Some evidence already points in this direction.

First, children who are better at decoding nonverbal, intentional information, or children who are better at interpreting expressions of facial affect, tend to have a more internal locus of control (Hall, Gaul, & Kent, 1999; Mufson & Nowicki, 1991; Nowicki & Duke, 1992; Strand & Nowicki, 1999). Differences in the degree of empathy (undoubtedly a valued social skill) may also differ between children who differ in control perceptions. Empathy is reported to be strongly related to effortful control measures, with children high in effortful control showing greater levels of empathy (Rothbart et al., 2000). If the presumption that effortful control is greater for internal children is correct, it would follow that these children are also capable of more empathic thinking. It would be interesting to investigate if effortful control supports empathy by allowing these internal individual to attend to the thoughts and feelings of others without becoming overwhelmed by their own distress.

Second, individual differences in locus of control in children may indeed reflect underlying differences in executive functions and socio-cognitive skills. For 168 children attending the 4th grade, locus of control scores obtained by a self-report questionnaire and by teacher ratings could be predicted by a factor derived from performance on various theory of mind tasks and by a factor derived from performance on the Tower of Hanoi task (Declerck & De Brabander, unpublished manuscript).

Third, an internal locus of control in adults tends to be an indication of skilful social interactions, which may in turn reflect superior social cognition. Lefcourt and colleagues found that those individuals who scored more internal on the Affiliation Locus of Control scale were also better social interactors when discussing their experiences after having viewed a stressful film (Lefcourt, Martin, Fick, & Saleh, 1985). Additional research to test whether internally oriented people make better social judgments would help to bring light to this issue.

A final, indirect indication that locus of control and theory of mind may be related is through their mutual correlation with the frontal executive functions. Many studies have assessed the role of executive function in theory of mind (Perner & Lang, 1999), and their possible temporal interactions during development. Generally, among normally developing children, improved performance on theory of mind tasks seems to parallel progress in executive functions (Hughes, 1998a; Perner & Lang, 1999; Perner & Lang, 2000; Perner, Stummer, & Lang, 1999). But not surprisingly, many of the false belief tasks used to assess theory of mind abilities may rely heavily on working memory (Fathie & Symons, 2003; Hughes, 2002; Saltzman, Strauss, Hunter, & Archibald, 2000), so that the specific nature of the relation remains highly debated (Carlson, Moses, & Breton, 2002; Hughes, 1998a, 1998b; Perner & Lang, 1999; Russell, Mauthner, Sharpe, & Tidswell, 1991). Other authors have found no relationship at all between particular executive functions and specific theory of mind tasks (Perner, Lang, & Kloo, 2002; Rowe, Bullock, Polkey, & Morris, 2001; Tager-Flusberg, Sullivan, & Boshart, 1997), questioning the relation in general.

The relation between the executive functions (EF), social cognition in the form of theory of mind (TOM), and the locus of control begs the question regarding their possible chronological interdependence. Are the executive and social skills which correlate with individual differences in locus of control their antecedents, consequences, or incidental correlates, perhaps the result of activating the same brain areas? Longitudinal studies are needed to unravel these dynamics, as different lines of reasoning yield different possible scenarios. There may be reason to believe that EF and TOM develop first, given the evidence that some components of executive functions and theory of mind (e.g., joint attention) develop from the first year on, and that already during the second year of life the child is undergoing rapid cognitive changes (e.g., Flavell, 1999; Johnson, 2000; Johnson, Posner, & Rothbart, 1991; Posner & Rothbart, 2000; Rothbart et al., 1994). Krampen (1997) believes that the locus of control does not develop until later in childhood, because up till the age of 12, self- and environment-referring cognitions are not sufficiently developed, and are not stable parts of the mental capacity of children. An obvious reason for this is, naturally, the limited language ability and, their limited abstract reasoning which is needed to generalize across many situations. Thus, it could be that a lack of sufficiently developed frontal executive control (especially working memory and planning out an answer) delays the development of the expression of a particular locus of control orientation. In this scenario, the locus of control would become more internal only when one is able to obtain more relevant information in a more efficient way, and because one is better able to delay gratification or exert self control. The locus of control tends indeed to become more internal with age (Penk, 1969; Richaud de Minzi, 1991).

Alternatively, a person's locus of control orientation may be an expression of an infant's temperament, and hence be in place at a very early age, even if it cannot reliably be assessed with current measurement tools. In that case, control perception would be a precursor of social cognition, so that the locus of control might in turn affect performance on TOM and EF tasks. It is, to be fair, not unlikely that more internal children, due to their intentional stance, make better use of these functions in regulating their behaviour. This would become noticeable by superior performance on tests, especially in slightly competitive situations, or in situations involving rewards. In this scenario, the locus of control reflects more a motivational characteristic than a cognitive one, so that apparent superior EF and TOM capacities are the result of an innate locus of control orientation, which follows directly from emotion regulation. This view is compatible with the causal relation which was suggested by Crandall and Crandall (1983). They wrote that "perceptions of internal control, compared to perceptions of external control, are generally found to facilitate a more active search of the environment for information relevant to salient goals, superior cognitive processing and recall of that information, more spontaneous engagement in achievement activities, selection of lower challenging tasks, and better ability to delay gratification and to persist under difficulty."

Finally, the locus of control, EF, and TOM could all be the result of incidentally activating the same cortical network. These cortical areas are discussed next.

4. Neuro-anatomical basis for control perception

If our model is plausible, and social cognition and executive functions are indeed either antecedents, consequences, or mere correlates of control perception, their biological underpinnings in anatomy and neurochemistry are likely to play an important role in determining individual differences in locus of control. Therefore, by understanding which brain functions contribute to emotion regulation, executive and socio-cognitive skills, we may also gain insights in the neurological basis of the locus of control.

From the discussion so far it is clear that the prefrontal cortex is of vital importance for the human ability to self-regulate behaviour through executive functions and social cognition (e.g., Mesulam, 1998; Previc, 1999). While we realize that self regulation and ensuing control perception follow from functional connectivity in both frontal and paralimbic structures (see Tucker, 2001), to construct our model, we will limit ourselves mostly to three cortical brain regions: the dorsolateral and ventral prefrontal cortex and the anterior cingulate gyrus which connects the prefrontal cortex to limbic areas. The reasons are twofold. First, the model, however simplified, will be easier to test in future studies. And second, because the prefrontal portion is the area of the brain which underwent the most drastic expansion during primate evolution, it is a good structure to focus on when trying to explain features of our behaviour which are typically, or perhaps even uniquely, human. Mesulam (1998) points out that the prefrontal cortex makes no contribution to routine sensory, skeletomotor or autonomic function, but that it is "a luxury dividend that phylogeny offered primates and that catalysed the ability to transcend stimulus-bound existence." Likewise, it could be argued that "feeling in control" is a luxury dividend which seems to be unessential for the continued existence of most species on earth, yet of utmost importance for the psychological health of humans.

Understanding how the prefrontal cortex may be involved in assuming higher-level control (self-regulatory skills) over lower-level functions requires a short description of the functional anatomy of some of the frontal-subcortical networks. Cytoarchitectonically as well as, to a certain extent, functionally, clinical neuropsychologists often distinguish a dorsolateral prefrontal cortex region and a ventral prefrontal cortex region. The latter includes the ventrolateral and ventromedial/orbitofrontal cortex. The dorsolateral prefrontal cortex is part of the archicortex originating from neurons in the hippocampus and is involved in the spatial and conceptual reasoning process. The ventral prefrontal cortex is part of the paleocortex originating from neurons in the amygdala. It is furthermore highly connected with limbic nuclei and is more involved in emotional and social processing (Stuss & Levine, 2002).[8] A review of lesion studies suggests that lesions in the dorsolateral prefrontal pathway lead to cognitive executive control dysfunction, and that orbitofrontal lesions in the ventrolateral pathway tend to be associated with changes in the regulation of motivation and affect, or by changes in personality characterized by a lack of impulse control (Tekin & Cummings, 2002). It has been postulated that the dorsolateral cortex acts in concert with the orbitofrontal and ventromedial prefrontal cortex to solve diverse social as well as cognitive problems. The more possible outcomes there are given a particular environmental problem, the more responsive these regions becomes (Carter et al., 1998). If perceiving control involves reasoning through the outcome of one particular behaviour out of a range of possible alternative behaviours leading to different outcomes, it is likely to also involve activity in all of these prefrontal cortex areas.

Thus, through its contribution to both the executive functions and social cognition, activity in the dorsolateral and ventral cortex could also contribute to locus of control determination. Their relative contribution to the control of thoughts and actions will depend on the motivational significance of the context: more motivated behaviour would be driven by more ventromedial/orbitofrontal cortical involvement, while more abstract problem-solving behaviour would be driven by more dorsolateral cortical involvement.

We will next outline the major functions of the three cortical areas (dorsolateral prefrontal cortex, the ventral prefrontal cortex, and the anterior cingulate cortex) mentioned in Fig. 1. For each area, we will describe how its activation could contribute either indirectly (through emotion regulation, executive functions, or social cognition), or sometimes directly, to control perception.

4.1. Dorsolateral prefrontal cortex

4.1.1. Role in emotion regulation

Although the dorsolateral cortex is mostly implicated in abstract types of cognition, it is not completely unimportant with respect to experiencing emotions. Patients with dorsolateral cortical lesions often show a blunting in the emotional and motivational colouring of sensory experience (Mundy, 2003). Portions of the dorsolateral cortex may also modulate the impact of experience by encoding and evaluating the acquired significance of sensory events which are occurring (Mesulam, 1998).

4.1.2. Role in executive functions

The more typical functions of the dorsolateral prefrontal cortex are those of higher-level abstract cognition, such as working memory, analytical reasoning, and strategic planning (Stuss & Levine, 2002). In general the dorsolateral cortex tends to regulate cognition elicited by relatively abstract, decontextualized problems, more so than problems involving the regulation of motivated or affective problems (Zelazo & Muller, 2002). Thus, the dorsolateral cortex is often implicated as a region of major importance for the executive functions. Imaging studies, for example, show this region to be more activated compared to other regions during performance of the Tower of Hanoi (Cazalis et al., 2003), a task which assesses planning abilities. Tasks which require attentional set shifting (e.g., variations of the Wisconsin Card Sorting Task) have also been shown to activate the dorsolateral cortex, both by functional magnetic resonance imaging (fMRI), (Nagahama et al., 2001) and by positron-emission tomography (PET), (Rogers, Andrews, Grasby, Brooks, & Robbins, 2000). Brain imaging studies further indicate that the Stroop task, assessing impulse control, also involves the dorsolateral prefrontal cortex (Bench et al., 1993). Working memory as well is implemented to a great extent in the dorsolateral cortex (Goldman-Rakic, 1996; Petrides, 1996).

Recent findings regarding a particular area in the most anterior region of the dorsolateral cortex, Brodmann area 10, may shed light on how the acquired significance of sensory events becomes encoded (Mesulam, 1998). This area is highly connected to the medial temporal lobes and the hippocampus (Maguire & Mummery, 1999) and seems to be crucial in the formation of episodic memory (Tulving, 2002) and specifically in self-referencing (Kelley et al., 2002). Based on the existing theory and data from connectional and cellular anatomy, Ramnani and Owen (2004) have tried to formulate the role of Brodmann area 10 as "integrating the outcome of two or more separate cognitive operations in pursuit of a higher behavioural goal." To feel in control of an environmental event, one needs to integrate at least two separate cognitive processes: establishing a causal relationship between two events, and integrating it with the self concept at that time. At least in theory, the dorsolateral cortex seems well suited for this purpose.

4.2. Ventral prefrontal cortex

Case studies of patients with cortical lesions suggest that the ventral prefrontal cortex plays an important role in those aspects of self-regulation which involve reward processing, impulse control, and decision-making (Damasio, 1994). In patients with ventral prefrontal lesions, the deficits in decision-making can be either executive or social in nature.

4.2.1. Role in emotion regulation

The orbitofrontal cortex is important in emotion regulation as it seems to be required for affective decision-making. Both Damasio (1994) and Rolls (2000c) have described the orbitofrontal cortex as a processing site for the learned associations between affective stimuli and their reinforcement value (reward/punishment), hence playing a crucial

[8] A useful description of the functional anatomy of the frontal cortex, along with a review of clinical tests frequently used to assess frontal executive functioning, can be found in Stuss and Levine, 2002.

role in subsequent decisions. Rolls (2000b, 2000c) further suggests that, with its great expansion in primate evolution, the orbitofrontal cortex became especially involved in repeated learning of stimulus-reinforcement associations, more so than during initial learning (in which the amygdala may be more involved). Because of this role in repeated learning, the orbitofrontal cortex is well-suited for developing a locus of control based on a generalized expectancy pattern of outcomes across a range of situations.

4.2.2. Role in executive functions

The ventromedial cortex also plays a role in some of the executive functions, particularly the functions of impulse control as well as action-monitoring (Stuss & Levine, 2002). A PET study has found that the orbitofrontal cortex was also activated during the Stroop task (Bench et al., 1993).

A particularly relevant finding with respect to the locus of control concept includes the recent experimental investigations which indicate that the ventromedial prefrontal cortex is especially related to decision-making in familiar, but unstructured situations (Stuss & Levine, 2002). For example, functional neuro-imaging data have shown that the ventromedial prefrontal cortex becomes activated during tasks in which choices must be made in under-specified conditions (Elliot, Dolan, & Frith, 2000). Furthermore, Levine, Freedman, Dawson, Black, and Stuss (1999) describe a condition known as "self-regulatory disorder," characteristic of patients with ventromedial prefrontal cortex lesions. Patients afflicted with this disorder can no longer regulate their behaviour according to internal goals or constraints, and we would expect these patients to have an external locus of control. Levine et al. (1999) postulate that this condition arises due to the inability to hold a mental representation of the self on line, so that self-related information can no longer be used to inhibit inappropriate responses. Again, the impulsive behaviour associated with this condition is most apparent in common but unstructured situations, such as child-rearing, making a major purchase, or occupational decision making. Similarly, the locus of control construct is also based on developing generalized expectancies about the outcome of events in unstructured situations (Rotter, 1966), and individual differences in this trait are likewise most noted in situations as the ones just mentioned (see for example, McClun & Merrell, 1998; Morton & Mann, 1998, for child rearing, Busseri et al., 1998, for major purchases, and Luzzo, Funk, & Strang, 1996; Taylor & Popma, 1990, for career decisions).

4.2.3. Role in social cognition

The fact that the ventral prefrontal cortex is a core determinant of human social behaviour is perhaps best illustrated by the classic description of Phineas Gage's drastic changes in personality, following extensive damage in this region (Damasio, 1994). Descriptions of Gage's changes in social and emotional regulatory skills nicely illustrate a switch from an internal to an extreme external locus of control, the latter being responsible for the succession of failures in his life after the accident which caused the brain injury (Damasio, 1994).

The ventromedial and particularly the orbitofrontal prefrontal cortex play a crucial role in social cognitive skills. Imaging studies show that these areas are consistently activated during theory of mind tasks. This is true for tasks involving false belief (Gallagher & Frith, 2003; Stuss, Gallup, & Alexander, 2001) as well as interpreting eye gazes (Calder et al., 2003).

4.3. Anterior cingulate gyrus

A third cortical area which seems to be crucial for emotion regulation, executive functions, social cognition, and, according to our model in Fig. 1, feeling in control, is the anterior cingulate cortex (ACC). Lesions in the ACC lead to general apathy (Tekin & Cummings, 2002), while lesions in the ACC together with lesions of the dorsolateral prefrontal cortex lead to impairments of willed actions in particular (Devinsky et al., 1995). Finally, the combination of lesions of the ACC and of the orbitofrontal cortex result in a devastating "social agnosia," whereby personal and social judgements are completely impaired (Devinsky et al., 1995; Mundy, 2003).

Architectonically as well as functionally, the anterior cingulate gyrus is not a homogenous structure. It is highly connected to the limbic lobe on the one hand, and to the prefrontal cortex on the other hand. Thus, by recruiting both subcortical and cortical activation, the ACC is intrinsically involved in self regulation. Recent theories regard the ACC as a structure involved in evaluating conflicting demands signalling when and how executive functions subsumed by the dorsolateral prefrontal cortex should be implemented (Carter, Botvinick, & Cohen, 1999). Reviewing the electrophysiological studies involving the ACC during executive function tasks, Luu and Tucker (2003) suggest that the integral role of the ACC consists of action regulation. This process involves first learning which action is relevant in a given motivational state, monitoring the outcome of the action, and switching to a different set of actions when expected outcomes are violated. Because both the context and the response of an action may have affective components (in terms of punishment and reward), proper integration of emotion and cognition is required if subsequent learning of action-outcome associations is to be effective.

Being connected to both the ventral and the dorsolateral prefrontal cortex, the ACC may play an imminent role in the integration of the abstract cognitive processes performed by the dorsolateral prefrontal cortex, and the more emotional processes assumed by the ventral prefrontal cortex (Devinsky et al., 1995). For example, cognitive tasks tend to activate the dorsal portion of the ACC and deactivate the rostroventral ACC, while emotional tasks tend to activate rostroventral ACC and deactivate the dorsal ACC (Bush, Luu, & Posner, 2000).

This integrative role of the anterior cingulate gyrus can also be deduced from another interesting finding:

functional imaging studies show that increased activity in the anterior cingulate cortex is usually observed before the onset of the task, at the time the subject finds out that a difficult task is about to follow (Murtha, Chertkow, Beauregard, Dixon, & Evans, 1996). This is also consistent with the finding that activity in the anterior cingulate cortex is related to our awareness of a specific feeling rather than to the feeling itself. For example, anterior cingulate activity is more related to the expectation of a painful feeling than to the intensity of the stimulus which is inducing the pain (Rainville, Duncan, Price, Carrier, & Bushness, 1997). Relating this particular finding to the locus of control, internally oriented patients with chronic myofascial pain report less intense pain compared to externally oriented patients who experience pain of the same origin (Toomey, Mann, Abashian, & Thompsonpope, 1991) There is also evidence that the locus of control is generally related to differences in pain perception (Williams, Golding, Phillips, & Towell, 2004). Since the locus of control is based on the perception of a feeling of control, rather than on actual control, it is possible that perceiving control requires simultaneous cognitive and emotional processing, which would be made possible by the anterior cingulate gyrus.

4.3.1. Role in emotion regulation

To begin with, there is growing evidence for the anterior cingulate gyrus' contribution to emotional processing from fMRI studies performed during the emotional Stroop task (Whalen et al., 1998).

The ACC has also been postulated to play a major role in determining a child's temperamental traits which lie at the roots of later affective behaviour and perceived control (Posner & Rothbart, 2000). For example, Chorpita and Barlow (1998) rely on a mechanism of selective attention[9] located on the anterior cingulate gyrus when describing how paying too much attention to the aversive, uncontrollable stimuli may result in low perceived control, setting the stage for low perceived control later on in childhood and adulthood. Their description is reminiscent of Posner's concept of an "executive attention" system, also located on the anterior cingulate gyrus (Booth et al., 2003; Posner, 1995; Posner & Petersen, 1990; Posner & Raichle, 1994; Posner & Rothbart, 1998, 2000). Specifically, Posner and Rothbart (2000) suggest that the anterior cingulate gyrus may become involved in a control system for emotions if newborns learn, often through repeated interactions with a caregiver, to control their moments of distress by shifting attention away from the source of distress. At this age, the periodic shifting of attention may become associated with emotional states through repeated amplification of activity in the anterior cingulate gyrus, being strongly connected to the limbic nuclei where emotional reactions are initiated.

Of particular interest with regard to control perception is the finding that highly emotionally reactive females show reduced anterior cingulate activity when processing unsolvable tasks (Bauer, Pripfl, Lamm, Prainsack, & Taylor, 2003). From this finding, the authors speculated that loss of control and learned helplessness are a state in which the function of the anterior cingulated is no longer maintained. Limbic areas (and particularly the amygdala) would inhibit the anterior cingulate gyrus to send signals to the prefrontal cortex. Without this input which monitors the conflicts among different brain regions, the prefrontal cortex would no longer be able to guide behaviour towards a goal (Carter et al., 1999).

4.3.2. Role in executive functions

Activation of the anterior cingulate gyrus seems to be required for planned actions (Devinsky et al., 1995; Hunter et al., 2003; Mundy, 2003), and in all types of decision-making (Tekin & Cummings, 2002), especially those involving conflicting demands (Carter et al., 1999). Positron emission tomography (PET) studies in adults have consistently revealed increased activity in this midfrontal area during tasks which require quick decision-making skills, such as shifting tasks (i.e., Wisconsin Card Sorting) and conflict resolution (i.e., Stroop-related) tasks (Bench et al., 1993; Berman, Ostrem, Randolph, Gold, & Goldberg, 1995; Bush et al., 1998; Pardo, Pardo, Janer, & Raichle, 1990; Posner & DiGirolamo, 1998; Weissman, Giesbrecht, Song, Mangun, & Woldorff, 2003).

Other executive functions, such as the planning involved in building the Tower of Hanoi, also activate the anterior cingulate gyrus (Cazalis et al., 2003). In children, performance on this particular task has already been shown to correlate to locus of control, with internals outperforming the externals (Declerck & DeBrabander, unpublished manuscript).

Electrophysiological studies point to the ACC's role in action-monitoring. Luu and Tucker (2001) report that EEG recordings of the scalp show the occurrence of a negative event-related potential (error-related negativity or ERN) soon after the subjects make an error. This ERN is located in the centromedial frontal cortex corresponding to the anterior cingulate gyrus. Interestingly, the ERN occurs only when a subject is aware of making an error, suggesting a specific role in self-monitoring along an affective dimension (Luu, Flaisch, & Tucker, 2000). This is further corroborated by Luu et al.'s (2000) finding that the amplitude of the ERN increases linearly as responses are occurring progressively later during tasks in which late responses are also scored as errors (for example, during a deadline imposed-response task). Similar event-related potentials to the ERN

[9] To describe this selective attention system, Chorpita and Barlow borrow Gray and McNaughton's (1996) concept of a comparator. This is described as a subsystem of the subcortical-frontal Papez pathway with neurons terminating in the anterior cingulate gyrus. Its role is to assess the current situation, plan an action if needed, store the resulting behavioural outcome, and finally, compare the current outcome with regularities obtained from previous behavioural outcomes. These "stored regularities" are, according to Chorpita and Barlow (1998, p. 4), established during early development and are key to the perception of control later on. We believe that the flexible and goal-directed behaviours associated with an internal locus of control are compatible with the functions described by a "comparator."

have been observed at ACC locations following negative feedback or unexpected losses in gambling tasks (Gehring & Willoughby, 2002), yielding additional evidence for the ACC's role in self-monitoring in accordance with current emotional states.

Individual differences in frontal electrophysiology of self-monitoring are consistent with the difference in behaviour one would expect between people with an internal and external locus of control. Self-monitoring, as illustrated by ERN, is aberrant in certain personality disorders related to the dimensions of affect or distress. Unusually small ERN's have been reported for people scoring low on trait socialization (indicating low sociability and low levels of anxiety) and in people receiving an anxiolytic drug (reducing anxiety). In contrast, a larger than usual ERN is observed in people with obsessive-compulsive disorder and in people who score high on the dimension of negative emotionality and subjective distress (Luu et al., 2000; Luu & Tucker, 2001; Luu & Tucker, 2003). Although no studies have looked specifically at the relation of EEG patterns during executive functions and locus of control, the findings reported so far are consistent with the idea that low perceived control would correspond to either excessive self-monitoring (leading to high distress) and large ERN's, or to extremely low levels of self-monitoring and unusually low ERN's, associated with a lack of concern with the negative consequences of one's actions.

A final important observation with respect to the role of the ACC in locus of control determination is that the anterior cingulate gyrus is found to be more activated during cooperative play in a prisoner's dilemma game (Rilling et al., 2002). Playing cooperatively in a strategic game with repeated interactions can be considered a consequence of the executive function of impulse control, as it requires that one can look ahead and choose a strategy with fewer immediate pay-offs but possibly a greater reward in the long run. Individuals with an internal locus of control tend to have more impulse control (see references earlier) and have also been reported to play more cooperatively in an iterated prisoner's dilemma game compared to those with an external locus of control (Boone et al., 1999a).

4.3.3. Role in social cognition

Brain imaging studies have also indicated that the anterior cingulate gyrus is consistently activated during theory of mind tasks (Calarge, Andreasen, & O'Leary, 2003; Gallagher & Frith, 2003; Vogeley et al., 2001). The specific contribution of the anterior cingulate gyrus to social cognition may be through its role in initiating joint attention in infancy, and social orienting later in life (Mundy, 2003).

5. Neurochemical basis for control perception

An anatomical region by itself cannot support a behavioural function or skill. Functions are driven by neurochemical processes occurring along pathways in those regions. While many neurotransmitters are likely to contribute to the human ability of feeling in control, we will limit this discussion to the role of the neuromodulator dopamine, because of the available data (direct and indirect) accrued so far.

Dopamine is one of the biogenetic amines, a phylogenetically old class of chemicals which is widely distributed within the CNS and modulates brain functions associated with behaviours such as emotions, motivation, and cognition. Five different dopamine receptors have been identified falling into 2 classes (D1 and D2), each with a distinct pharmacological profile and a unique neuro-anatomicaldistribution (Farde, Gustavsson, & Jonsson, 1997). The genes coding for these receptors are often polymorphic, and some of the polymorphisms have been associated with specific behaviours (Fan, Fosella, Sommer, Wu, & Posner, 2003). Individual differences in the distribution and densities of dopamine receptors within the CNS have also been documented (Farde et al., 1997). All these properties make dopamine a prime candidate for linking individual differences in neurotransmission to personality traits (Le Moal & Simon, 1991). A specific link between D2 and D4 polymorphisms has already been indicated for novelty seeking (Ding et al., 2002; Noble et al., 1998; Strobel, Wehr, Michel, & Brocke, 1999; Suhara et al., 2001), extraversion (Depue & Collins, 1999; Depue, Luciana, Arbisi, Collins, & Leon, 1994; Rammsayer, Netter, & Vogel, 1993), detached personality (Farde et al., 1997), and the determination of 2-month old infant temperament (Auerbach et al., 1999). As far as we know, there are not yet any studies which show a direct link between dopamine receptor genes and difference in locus of control or any other psychometric measures of perceived control.

The explosive data on the role of dopamine modulation of behavioural functions reveals a very complex picture. However, it is noteworthy that from a recent review on prefrontal cortex dopamine functioning (Seamans & Yang, 2004), it appears that all types of actions resulting from stimulation of D1 dopamine receptors (which are the most common) augment the robustness of working memory representations. Earlier we mentioned how Mesulam (1998) viewed working memory as the essential component allowing organisms to self regulate, pursue goals over time, and gain control over their environment. Therefore we can already speculate that one of the possible influences of dopamine in control perception will be accounted for by its relation to working memory and its role in maintaining or changing goal representations in accordance with changing environmental conditions. Throughout this paper, we have repeatedly argued that individual differences in flexible, goal directed behaviour is key to understanding differences in locus of control.

We realize that a model of personality based on only one neurotransmitter is too simplistic. Furthermore, given the broad scope of this review, it is not our intent to give a detailed description of the mechanism whereby dopamine activity could explain control perception and individual differences in locus of control. Although it is clearly important to understand the mechanisms of prefrontal dopamine modulation in order to gain deeper understanding of how it may contribute to individual differences in control perception, a thorough review of the subject is beyond the scope of this paper. For a more detailed review of how dopamine activity can affect specific behaviours associated with personality structure we refer to the review of Depue and Collins (1999) on extraversion. The aim of our review is to provide a first step towards a more integrative approach to the study of personality and span the different level of analyses (predisposed abilities, anatomy, and chemistry) which are necessary to arrive at a meta-process such as feeling in control. Therefore, we will emphasise the integration of anatomy and neurochemistry, and limit the discussion to follow primarily to the patterns of cortical innervation where dopamine is known to play a mediating role.

Thus, the focus of this section is on how control perception may be associated with patterns of cortical activation of different dopamine neural pathways. These pathways connect frontal cortical areas with (among other structures) the striatum, the subtantia nigra, and the ventral tegmental area in the midbrain (Alexander, DeLong, & Strick, 1986; Seamans & Yang, 2004). Three major subcortical-frontal pathways are recognized: the nigrostriatal, mesocortical, and mesolimbic pathways. The functions which have been associated with these pathways indicate that dopamine neurotransmission in all of these pathways underlies those processes which make emotion and behavioural regulation, and consequently, perceived control, possible (see Table 2).

The nigrostriatal pathway contains neurons originating in the substantia nigra and innervates the striatum, and from there the motor cortex (Iversen, 1977; Tekin & Cummings, 2002). Activity along this pathway modulates memory functions, motor coordination, (Jog, Kubota, Connolly, Hillegaart, & Graybiel, 1999), and habit learning (Knowlton, Mangels, & Squire, 1996). DA deficits along this pathway characterize conditions as Parkinson's and Huntington's disease impairments which may also be accompanied by loss of motivation (apathy), loss of cognitive functions, and personality changes (Mendez, 1994; Pillon, Czernecki, & Dubois, 2003; Shiwach, 1994).

The mesocortical pathway has neurons originating in the ventral tegmental area and terminating in the dorsolateral prefrontal cortex. It is believed to underlie the executive functions (Posner & Petersen, 1990; Tekin & Cummings, 2002; Tucker & Williamson, 1984). A relation between mesocortical DA and executive functions is suggested on many accounts. To begin with, the evolutionary size increase in the primate frontal cortex was accompanied by enhanced executive functions and social skills, as well as by a vast expansion of the mesocortical dopaminergic system (Previc, 1999). Especially the dorsolateral cortex and layer V of the anterior cingulate gyrus, regions which underlie some of the executive functions, are highly innervated by dopamine neurons (Lidow, Wang, Cao, & Goldman-Rakic, 1998). Experimental studies have shown that many of the frontal executive functions can be blocked by dopamine inhibitors (D'Esposito & Grossman, 1996; Diamond, 1996; Puumula & Sirvio, 1998; Robbins, 2000; Welsh, 1996). Social skills such as theory of mind abilities have also been postulated to be related to dopamine metabolism in this pathway (Abu Akel, 2003). Of particular interest with respect to the role of dopamine and individual differences in executive functions is the study of Fan et al. (2003). They found that two polymorphisms of the dopamine receptor gene DRD4 produced significant differences in the activation of the anterior cingulate gyrus. These polymorphisms had been previously associated with individual differences in reaction times during performance of an executive attention task. An fMRI study indicated that a person with the DRD4 allele associated with superior executive functioning showed increased activation of the anterior cingulate cortex while performing the task. Fan et al. conclude that "this finding closes the loop in showing that [dopamine receptor] genes involved in modulating behavioural performance influence brain activity in a node of the network that mediates that performance" (p. 7410).

The mesolimbic pathway has neurons originating in the ventral tegmental area (VTA), connects to limbic nuclei, to the anterior cingulate gyrus, and innervates the orbitofrontal prefrontal cortex (Le Moal & Simon, 1991; Tekin & Cummings, 2002). It plays an imminent role in the regulation of affective and appetitive behaviour (Mirenowicz & Schultz, 1996; Rolls, 2000b, 2000c; Schultz, 2002), and modulates the functions of sustained attention, impulse control, and incentive motivation (Le Moal & Simon, 1991;

Table 2
Some characteristics of three major subcortical-cortical dopamine pathways

DA pathway	Cortical innervation	Regulated functions	Reference
Mesocortical	Dorsolateral prefrontal cortex	Executive functions Social cognition	6, 7, 9, 10
Mesolimbic	Orbitofrontal prefrontal cortex	Attention Regulation Incentive motivation	4, 5, 8, 9, 10
	Anterior cingulate gyrus	Impulse control	
Nigrostriatal	Motor cortex	Motor coordination and motor impulse control Recall memory Habit learning	1, 2, 3, 9, 10

(1) Iversen, 1977; (2) Jog et al., 1999; (3) Knowlton et al., 1996; (4) Le Moal and Simon, 1991; (5) Mirenowicz and Schultz, 1996; (6) Posner and Petersen, 1990; (7) Previc, 1999, (8) Schultz, 2002; (9) Tekin and Cummings, 2002; (10) Tucker and Williamson, 1984.

Schultz, 2002). DA activity in the mesolimbic pathway has been implicated in approach behaviour and the personality construct of extraversion (Depue & Collins, 1999). Similar to our endeavor in this review, Depue and Collins establish a link between neural networks and neuromodulation, a mammalian behavioural facilitation system (behavioural approach system), and extraversion. Specifically, they explain how dopamine neurons originating in the VTA and integrated within the orbitofrontal cortical network encode the salience of events and thereby promote incentive motivation. This is consistent with Schultz (2002) account of dopamine's role in signalling a prediction error by comparing the expected and actual reward of stimuli. Based on a review of animal evidence, Depue and Collins further suggest that individual differences in the threshold to elicit incentive motivation can be attributed to genetic variation in the mesolimbic dopamine pathway originating in the VTA. Thus an individual with a relatively high number of dopamine neurons would be predisposed to establish a large number of synaptic contacts within the orbitofrontal cortex network. Across a lifetime, experience-expectant and experience-dependent processes would enhance the facilitation of dopamine-modulated responses to incentive stimuli, which would be manifested in a high and stable level of approach behaviour. In this way, the stability of interindividual differences in psychometric measures of extraversion could be understood. Because extraversion has consistently been substantially correlated to the locus of control (Fig. 2), and because the "agency" subcomponent of extraversion refers to the idea that one can control the outcome of personal events, a similar role of the mesolimbic dopamine pathway could be envisioned for individual differences in the personality trait locus of control.

In the next three subsections, we will address how the relative activation patterns of different dopaminergic pathways can be associated with control perception, and how individual difference in these activation patterns could lead to personality differences in locus of control. A postulated relation between dopamine activity and control perception (Section III in Fig. 1) will be advanced based on three premises: (1) the role of dopaminergic activation in the brain's regulation of attention and motor actions, (2) the asymmetric cortical distribution of dopamine neurons, and (3) correlations between locus of control and a number of behavioural markers of dopamine metabolism.

5.1. Dopaminergic activation in attention and action regulation

Our initial inkling that a personality trait related to feeling in control may stem in part from dopaminergic activity was instigated by a particular model accounting for how differences in the brain's neurochemical regulation of cortical activity may be related to differences in higher cognitive functions. This model originally described by Tucker and Williamson (1984), and later elaborated by Liotti and Tucker (1995), suggests that we may learn much of cognitive control, including our executive abilities and control over perceived causality, by studying the brain's control of attention systems. The essence of the model is that the regulation of internal (self-regulatory) versus external (perception-action) control of behaviour may be inherent in brainstem controls supporting noradrenergic (NE) arousal and dopaminergic (DA) activation. Noradrenergic arousal is an attention system which originates through activity in the locus coeruleus, has widespread innervations to the limbic systems and throughout the cortex (especially in the right lobe), and achieves its major attentional control by increasing habituation. The regulatory effect of right hemisphere noradrenergic arousal seems integral to the orienting response (see also Corbetta & Shulman, 2002). In contrast, activation is an attention system integral to motivationally directed motor action, and is regulated by dopaminergic neurons originating in the ventral tegmental area of the midbrain with connections to the motor cortex, anterior cingulate gyrus, and frontal cortex (especially in the left lobe). Conceptually, "activation" corresponds best with Posner's "executive attention system" (Posner, 1995; Posner & Petersen, 1990). Whereas arousal produces phasic increments in neural activity, activation operates in a tonic mode, creating a redundancy bias to maintain the current information content as well as the readiness to act. The repetitious input of information will eventually facilitate the coordination of a complex behavioural response, because tonic dopaminergic activity ensures that motor activity is no longer chaotic but rehearsed. Thus, a DA bias in the regulatory role of activation restricts the rate of change in information processing and promotes tight regulation of complex sequential motor movements (Schultz, 2002; Tucker, 1999). Similarly, Rolls (2000a), Schultz (2002) and Depue and Collins (1999) delineated how the activity of dopamine neurons from limbic to prefrontal cortical areas is related to the initiation of action and a general state of behavioural activation, in preparation for a "go" response. This "go" response lies at the roots of appetitive, or approach behaviour.

This activation–arousal model for the brain's self- regulation of attention is relevant when considering how individual differences in a personality trait such as the locus of control may arise. An individual's responsiveness to external stimuli may, in fact, be a key to understanding differences in personality, as has long been postulated for the introversion-extraversion construct (Depue & Collins, 1999; Eysenck, 1967; Gray, 1973). Differences between several temperamental traits have also been suggested on the basis of relative differences in DA mediated activation or NE mediated arousability (Cloninger, 1998). Tucker and Williamson (1984) themselves also apply their activation–arousal model to differences in personality. For example, they suggest that the routinization produced by the redundancy of activation may allow a person who uses this self-regulatory mode to achieve order and efficiency in a job or lifestyle, whereas a person relying more on arousal as self-regulatory control may have an advantage in global, or holistic, processing. The advantages of activation with respect to personality traits have been described by Tucker and Williamson as follows:

> "Emphasis on [dopaminergic] activation as a self-regulatory mode influences not only emotion and attention but memory and problem-solving as well… applied to cognitive operations occurring over time, a redundancy bias restricts change. Under optimal circumstances, this form of control facilitates sequential, highly determined cognitive processing, leading to decisions that are logical and deliberate rather than impulsive or intuitive…" (Tucker & Williamson, 1984, p. 209).

While arousal is a necessary property of brain regulation with respect to the orienting response, an over-aroused state, in combination with low activation, may lead to personality deficits which are typical for an external locus of control. Tucker and Williamson describe this state as follows:

> "There are interesting parallels between the external control facilitated by the enabling effects of NE pathways, and the external control required by the self-regulatory style of the extravert or hysteric. […] External control produced by a disproportionate influence of arousal is reflected in a hysteric's tendency to become caught up in novel situations, impulsively making intense relationships, and making radical changes in living circumstances. Arousal is sufficient to produce, but not maintain infatuations, leading to repeated adaptive failures […]. Lacking the internal control of activation, the person operates with an incomplete set of adaptive cybernetics and can only self-regulate through being aroused by the emotional stimulation of the current environmental context" (Tucker & Williamson, 1984, p. 208).

5.2. Hemispheric and dorsal/ventral asymmetry

This local (detailed and sequential) versus global (holistic and emotional) processing is reminiscent of the distinction which is often made between left hemisphere and right hemisphere functioning. An additional aspect of Tucker and Williamson's model postulates that activation and arousal also tend to be lateralized processes, due to the asymmetric distribution of NE and DA pathways in the cortex. Many experimental and clinical studies and descriptions of patients with brain lesions have indeed confirmed that in primates DA tends to be more abundant in the left hemisphere and NE in the right hemisphere (reviewed in Heilman, 1995; Posner, 1995; Robbins & Everitt, 1995; Tucker & Williamson, 1984; Wittling, 1995). If these neurochemical (DA versus NE) pathways prove to be significant in determining personality differences, then the asymmetric distribution of these neurochemicals is also expected to lead to predictable differences in the cognitive functions they sustain among individuals with varying personality traits. With respect to the locus of control, hemispheric asymmetry between internals and externals has been suggested based on differences in left versus right hemispheric skills and in sensitivity towards negative affect. Internal adults and children tend to show superior performance in verbal tasks such as verbal fluency, verbal comprehension, and verbal reasoning, (Brecher & Denmark, 1969; Lefcourt, Gronnerud, & McDonald, 1973; Sawyers & Moran, 1984; Wildstein & Thompson, 1989), skills which rely on capacities of the left hemisphere (as shown by many experimental and neuro-imaging studies, see Hellige, 1990; Posner & Raichle, 1994; Springer & Deutsch, 1985). Internals also tend to have better developed executive functions. These frontal executive functions are also more sustained by the left hemisphere (Perner & Lang, 1999).

Externals tend to be more prone to feelings of negative affect and depressive tendencies (e.g., Benassi, Sweeney, & Dufour, 1988; Burger, 1984; Ganellen & Blaney, 1984; Hale & Cochran, 1987; Pruessner, Hellhammer, & Kirschbaum, 1999; Uhlmann & Froscher, 2001; Wiebe, 1991), they also show more characteristics of learned helplessness (Boone et al., 1990; De Brabander, Gerits, & Hellemans, 1997; Declerck et al., 2002) and have more suicidal tendencies (Lester, 1989; Martin, Richardson, Bergen, Roeger, & Allison, 2005; Pearce & Martin, 1993; Sidrow & Lester, 1988). Al these symptoms tend to correspond to increased EEG activity in the right hemisphere (Bell, 1998; Davidson, 1995; De Brabander et al., 1997; Tomarken, Davidson, & Henriques, 1990).

This left versus right hemisphere account for differences in control perception is compatible with the neuro-anatomical evidence suggested earlier which attributed self regulation to the integrative role of the anterior cingulate gyrus connecting the limbic system to the dorsolateral and ventral prefrontal cortex. Liotti and Tucker (1995) reasoned that the right hemisphere elaborated the spatial and configurational cognitive skills of the dorsal corticolimbic pathways (connecting to the hippocampus and posterior cingulate cortex), whereas the left hemisphere elaborated the object and analytical skills of the ventral corticolimbic pathways (connecting to the amygdala, orbitofrontal, and rostroventral anterior cingulate cortex). To understand the implications of this right hemisphere, dorsal corticolimbic, versus left hemisphere, ventral corticolimbic asymmetry for self control, Luu and Tucker (2003) drew on Gabriel' model of learning. Similar to reinforcement training in animals, they postulate that, during human cognitive studies, task-related instructions prepare the subject for action-selection. The dorsal corticolimbic pathway (involving the posterior cingulate cortex (PCC) and the hippocampus) selects actions based on the current behavioural context. As long as the environmental context remains stable, actions can be determined by this "external" form of control. However, when conflict is perceived, or when rapid adaptive changes are required (as in emergency situations), the ventral corticolimbic pathway (including the ACC, with input from the amygdala) allows for switching of actions in line with the current motivational context. This reasoning suggests that those action plans stemming from the PCC and the dorsal corticolimbic pathway (controlled by the right hemisphere) are context-dependent and more typical of external perceived control. When expectancies are violated (e.g., as signalled by the dopamine prediction-error initiated in the ventral tegmental area (VTA), see Schultz, 2002), the ACC and ventral corticolimbic pathway become engaged (controlled by the left hemisphere) and action planning becomes dissociated from the current context. This appears to be particularly important for fast adaptation. Viewing the limbic based cortical pathways in this way is fully compatible with PET and fMRI studies reported earlier indicating ACC activity in tasks requiring motivation, attention, self control, conflict resolution, and task switching. It further suggests that corticolimbic pathways are an important aspect of control perception, and that internal control may arise out of a primitive system of action regulation (Luu & Tucker, 2003).

The ventral corticolimbic pathway's role in task switching, fast adaptation, and internal perceived control is furthermore compatible with dopamine's postulated computational role in reinforcement learning, whereby the goal is to maximize the total future reward (Montague, Hyman, & Cohen, 2004). Neurons originating in the dopamine rich VTA region code the "incentive salience" of stimuli by mediating the "binding" between the evaluation of stimuli and the assignment of these values to objects or acts (Berridge & Robinson, 1998). Montague et al. (2004) rely on the "gating hypothesis of dopamine" to describe how this incentive salience forms the basis for the prefrontal cortex's cognitive control, guiding behaviour according to internally represented goals or actions. When a stimulus in the environment indicates that a more valuable reward can be obtained, VTA dopamine neurons initiate a process whereby the prefrontal cortex receives a signal indicating to update its goal representation and redirect behaviour towards achieving the new goal.

A model by Holroyd and Coles (2002) proposes that this error signal carried by the midbrain dopamine system serves as a negative reinforcement signal which elicits the event related negativity (ERN) in the anterior cingulate gyrus (see Section 4.3.2), thereby initiating the process of modifying the task at hand. To evaluate their proposition, Holroyd and Coles (2002) formulated two simulations and compared the output of these simulations with the results of two ERP experiments where participants are performing actual tasks. The simulated and empirical results were found to be very similar, lending support to their model. Thus, it appears that the ACC's role in task switching and action regulation is also under the control of midbrain dopamine modulation.

Depending on the pattern of dopamine innervation in both VTA and prefrontal cortex, as well as on the prior history of reinforcement learning with like stimuli, individual differences are expected in coding the incentive salience of stimuli and in the threshold at which neurons will fire to elicit signals to be sent to the prefrontal cortex, initiate the ERN, and redirect behaviour. As was discussed in Section 4.3.2, individual differences in the magnitude of the ERN have been reported several times. Failure to appropriately update goal representation will lead to perseverative behaviour, whereas failure to adequately maintain them will result in distractibility.

The idea that dopamine activity in corticolimbic pathways contributes to internal control perception was further examined by De Brabander et al. (De Brabander & Boone, 1989; De Brabander, Boone, & Gerits, 1992; De Brabander et al., 1990a, De Brabander, Gerits, & Boone, 1990b). Their experiments were meant to assess if internals would have a tendency to show more focused attention when primarily the left hemisphere/ventral pathway is engaged in an object recognition task, while externals would have a tendency to be more aroused when primarily the right hemisphere/dorsal pathway is engaged in a visuospatial navigation task. As predicted, during a sustained attention type task the reaction time was found to be faster for internals when a semantic decision had to be made, while it was faster for externals when a spatial decision had to be made (De Brabander et al., 1992). This suggests that the pattern of cortical activation during a sustained attention type task may be different for internals compared to externals: internals show more tonic activation during a semantic task, which engages primarily the left hemisphere.

To test whether externals are also more easily distracted, De Brabander and Boone (1989) presented an unexpected and irrelevant priming stimulus prior to the task stimulus during the visuospatial task. By creating a burst of arousal, this irrelevant and distracting stimulus indeed increased reaction times significantly more among the externally oriented participants. In addition, they also found that, after the presentation of the unexpected priming signal, externals showed elevated EMG activity in the left forearm compared to internals (De Brabander et al., 1990a, 1990b). When this same irrelevant priming stimulus was presented during the semantic task, however, reaction times were significantly decreased. In this task, the distracting signal seemed to stimulate focused attention and goal preservation rather than increasing perceptual arousal and distractibility, and it did so significantly more for the internally oriented individuals. The results of these two experiments suggest that externals are more disturbed by irrelevant noise, especially during a visuospatial task engaging primarily the right hemisphere. In contrast, internals tend to have a more effective selective attention system which becomes especially obvious during a left hemisphere semantic task. These results can be interpreted to be compatible with the hypothesis that externals rely primarily on dorsal corticolimbic, right hemisphere/global processing based on orienting and a habituation bias, while internals rely more on ventral corticolimbic, left hemisphere/local processing based on a redundancy bias promoting vigilance, motor readiness, and action regulation.

5.3. Correlations between locus of control and behavioural markers of dopamine metabolism

But are the differences in activation and arousal between internally and externally oriented individuals due to differences in frontal dopaminergic innervation? Although we are far from a definite answer to this question, some lines of research point indeed towards a possible role of dopamine in locus of control orientations.

First, De Brabander and Hellemans (1997) tested for differences in latent inhibition between internals and externals. Latent inhibition is the phenomenon where the capacity for a neutral stimulus to become a conditioned stimulus is reduced because the stimulus was previously experienced as irrelevant. Many neuropsychological studies indicate that latent inhibition can be blocked by increasing central dopamine levels (Weiner, 1990). Participating students again performed a semantic task. They were first exposed to 30 trials where the task stimulus was preceded by an irrelevant cue. In the next 30 trials (the latent inhibition condition), the irrelevant cue became suddenly (and unbeknownst the participants) a warning stimulus, indicating that a response (pressing the space bar) would soon be necessary. If the participants became aware of this contingency between warning and task stimulus, the reaction time would naturally decrease. The results showed that the effect of latent inhibition was substantially less for the internal individuals. This suggests that, during left hemisphere activation, an internal person is more likely to establish a new contingency between two stimuli, even if a while earlier one of the stimuli was irrelevant.

Second, a non-invasive way to assess a possible relation between locus of control and dopamine is to investigate the patterns of eye blink rates among different people in different situations, because spontaneous eye blinks are at least in part controlled by dopaminergic processes (Blin, Masson, Azulay, Fondarai, & Serratrice, 1990; Caplan, Guthrie, & Komo, 1996; Maclean et al., 1985; Taylor et al., 1999). Spontaneous eye blinking indices of dopamine D2 receptors have previously been significantly correlated to the personality trait of extraversion (Depue et al., 1994) Recently, Declerck, De Brabander, and Boone (2006) have counted the number of spontaneous eye blinks in 50 undergraduate students and 24 children's interviews, and related this to the nature of the question (memory-related, problem-solving, or self disclosure), as well as to the locus of control. The locus of control of the interviewee correlated significantly with blink rate, while the nature of the question did not. Internal children and adults alike were found to have higher blink rates, across all conditions. This finding is therefore also suggestive of a relation between internal control perception and tonic DA activity.

Third, De Brabander and Declerck (2004) used plasma level of the dopamine metabolite, homovanillic acid (HVA), as another marker to assess if there is a relation between dopamine metabolism and locus of control. Increased tonic levels of plasma HVA has consistently been found to be a marker of abnormal central dopaminergic functioning in schizophrenia research (Sumiyoshi et al., 2000). The population sample in De Brabander and Declerck's study consisted of 29 primary breast cancer patients on the day of hospital admission, prior to receiving the diagnosis of cancer. In this study, however, the data indicated that higher levels of pHVA were significantly associated with a more external locus of control.[10]

To explain this relationship, De Brabander & Declerck relied on a model of central dopamine regulation put forward by Grace (1991, 1993). This model possibly accounts for the cortical processes which could eventually lead to differences in cognitive styles and ultimately, personality. The model differentiates between dopamine activity in the prefrontal cortex and in the striata and limbic areas. Limbic and striatal dopamine is released phasically, while the control of this release resides in an inhibitory feedback loop involving tonic dopamine activity in the prefrontal cortex. A reduction in tonic, prefrontal dopamine activity has repeatedly been inversely related to high phasic levels of dopamine in subcortical brain area's (Breier, 1993; Iwano, Yamamuro, Hori, Yamauchi, & Nomura, 1997; Wilkinson, 1997). In addition, the "gating hypothesis of dopamine" suggests that, in the absence of subcortical phasic dopamine release, the prefrontal cortex is allowed to maintain its current goal representation against impinging sources of interference. The role of dopamine in this gating system is that it provides a mechanism for learning which signal is important enough to elicit a signal to update goal representations in the prefrontal cortex (Montague et al., 2004). It is conceivable that internally oriented people would have a "tightier" dopamine regulation system in the prefrontal cortex, consistent with their greater focusing abilities. The higher distractibility of externally oriented people may then correspond to a greater number of gating signals and a higher level of phasic subcortical dopamine release.

It should be noted, however, that a high tonic dopamine redundancy bias may in certain circumstances also predispose a person to anxiety and to a loss of control, in the same way that amphetamine abusers may show overly focused attention, hypervigilance, and paranoia (Tucker, 2001; Tucker & Williamson, 1984). This would imply a curvilinear relationship between dopamine on the one hand,

[10] Two additional pieces of evidence suggest that the relation between dopamine and locus of control were not caused by stress. First, there was no significant relation between locus of control and pMHPG, the brain's main metabolite for neorepinephrine. pMHPG and norepinephrine depletion has often been considered as a marker of depression, as it signals a shortage in norepinephrine in the central nervous system. Second, the reported result is from an analysis in which various other stress-related variables were partialled out (a measure of chronic stress assessed with Hopkins Symptom Check List, a measure of depressive mood, and the patient's own expectation of the results of the biopsy—i.e., whether or not the tumor would be malignant).

and anxiety and locus of control on the other hand: at low and normal levels of dopamine modulation, anxiety is associated with an external locus of control. But when the redundancy bias of dopamine modulation becomes excessive (as is the case in schizophrenia, mania, or extreme stress), it may also lead to hypervigilance, high levels of anxiety, and external control delusion in which the personal sense of agency is lost.

The difficulty in explaining the direction of the relation between locus of control and dopamine activity is not so surprising given some of the recent developments in the field of dopamine research showing that the functional regulation by dopamine pathways in the central nervous system is highly convoluted and complex, yielding contradictory results depending on the conditions of the experiments (Schultz, 2002; Seamans & Yang, 2004). Similarly, even if many mental illnesses (e.g., schizophrenia) are knowingly associated with dopamine dysregulation, they can not yet be diagnosed by biological assays (Montague et al., 2004).

6. A conceptual model and final considerations

We now return to the summarizing working model of the behavioural outcomes, the behavioural functions or abilities, and the neural correlates of feeling in control shown as in Fig. 1.

With this model, we try to conceive some of the brain functions which are likely to account for individual variation in control perception. First, individual differences in dopamine neuromodulation could be the result of differences in genotype, as several polymorphisms have already been described and receptor densities across different brain areas are known to vary among people (Fan et al., 2003; Farde et al., 1997). This could lead to variation in the extent of prefrontal synaptic contacts that become established, leading to differences in the patterns of dopamine neuromodulation along the mesolimbic, mesocortical, and nigrostriatal pathways. In addition, experience dependent processes can further add to differences in the threshold that is required to generate activity in each of these pathways. This would predispose people for different patterns of cortical activation. Activation of the dorsolateral cortex would support primarily abstract cognitive information processing, resulting in executive skills such as planning, working memory, and strategic thinking. Activation of the ventral and medial orbitofrontal cortex supports primarily socio-emotional information processing, resulting in social cognitive skills like a theory of mind. Activity in the anterior cingulate gyrus would ensure proper coordination of cognitive and socio-emotional processing, so that decision-making can be properly evaluated according to the physical and social demands of the environment. Because the anterior cingulate gyrus regulates attention and subsequent actions and appears to be involved in deciding which stimuli are relevant, selectively switching attention to those relevant stimuli, and monitoring the results of subsequent responses (Mundy, 2003; Luu & Tucker, 2003), we believe this region to be a major contributor to feeling in control. Feeling in control would therefore depend on the situational demands as well as on individual propensities in abstract and socio-emotional types of intelligences. As any personality trait, the latter would naturally also be influenced by social learning and other environmental conditions. These would enhance or diminish pre-existing tendencies (resulting from genotype driven or experience-based differences in dopamine modulation) which are expressed through varying combinations of social and executive skills and the regulation of emotions.

The behavioural outcomes of feeling in control is what we believe to be a normal, or healthy personality, characterized by emotional stability and happiness rather than anxiousness, by goal-directed and flexible behaviour, and by the capacity for learning and assimilating information.

A possible drawback of the current model, however, is the static and linear representation of neuromodulatory effects on behaviour. While the model explains the possible origins of general trait differences in control perception, it does not address the possibility of feedback mechanisms which may account for non-linear adaptations in control perception given changing environmental circumstances. That is, a person's internal, self regulatory control biases can be integrated with feedback processes involving sensory (or externally controlled) information. This would mean that internal and external locus of control can also be viewed more dynamically as the result of differing forms of self regulation achieved by the neurocybernetic mechanisms (DA and others) that negotiate between the motives imposed by the limbic core and regulated by the ventral pathway, and the environmental constraints represented in the neocortex (Goldberg, 1985; Tucker, 2001).[11] Consequently, state changes in locus of control are also expected. We turn to this topic in the next section.

6.1. Intra-individual fluctuations in locus of control

The previous account of how inter-individual differences in locus of control might arise can also account for intra-individual differences in control orientations. Although the locus of control tends to be a stable personality trait over time (Malia et al., 1995; Wolfe & Robertshaw, 1982; Wight, Aneshensel, Seeman, & Seeman, 2003), scores may fluctuate to represent real changes in momentary control perception. People may alter their locus of control seemingly at will depending on the time and situation (e.g., after divorce, Doherty, 1983) or a promotion (Harvey, 1971), or a severe illness (Sortie & Sexton, 2004). Yet these fluctuations are

[11] Tucker (2001) presents a core-and-shell model describing how cortico-limbic architecture is particularly well-suited to accommodate both action regulation towards an internal goal (via the motivational control of the limbic core), and self-regulation according to an enduring experiential base formed by the capacity of the neocortex to form new representations of sensory and motor information.

more likely reflective of changes in state, and do not need to invalidate locus of control as a trait. We have suggested that control perception can be considered a durable trait because (among other things) people differ systematically with respect to DA activation along corticolimbic pathways. Individual differences in dopamine receptor densities are indeed well established, and this density is furthermore constant across all dopamine cell groups in the brain (Fink & Reis, 1981; Le Moal & Simon, 1991; Oades, 1985).

The state-fluctuations in locus of control measurements (e.g., Lefcourt, 1991) can be explained (1) on a behavioural level, through its association with emotion regulation and the executive function of impulse control, or (2) on a neural level, through its association with the cortical regulation of attention.

To address the first, behavioural level issue, we rely on Muraven and Baumeister's (2000) concept that general self control is an exhaustible resource. Knowing that locus of control orientations correlate strongly with impulse control (Table 1), we expect that during stressful times, when emotion regulation is more demanding, both self control and locus of control of a person may be affected. Thus, while the locus of control orientation of a person may be stable enough to predict that person's behaviour across many situations, a moment to moment assessment may show intra-individual variation which is reflective of intra-individual variation in self control. (Muraven & Baumeister, 2000).

The second, neural level explanation of intra-individual differences in locus of control follows from Tucker and Williamson's (1984), Liotti and Tucker (1995), and Luu and Tucker's (2003) models we presented earlier. Just as dopaminergic activation and noradrenergic arousal are regulated depending on ecological demands of the environment, people can alter their perception of control (from more internal to external) depending on the situation: tight motor control and vigilance could be made possible through a redundancy bias created by DA regulatory activity, while enhanced perceptual receptivity and the orienting response may be due to the NE habituation bias, so that novel environmental information is selected for input. Similarly, action regulation by the dorsal corticolimbic circuit and the PCC may promote steadiness as long as current behaviour is adaptive, while the ventral corticolimbic pathway and the ACC may induce internal control and action switching in situations of conflict. Depending on the environmental situation, the task at hand, or the person's current emotional state, one or the other regulatory mechanism may predominate, accounting for temporary variation in the personal perception of control.

6.2. Summary and concluding thoughts

In this paper, we developed the hypothesis that the ability to feel in control results from dopaminergic cortical innervation, and the associated patterns of cortical activation, along with the ensuing emotional regulatory functions and social and executive abilities.

In addition to social learning, we have attempted to identify components involved in perceiving control over the outcome of meaningful events in life on a behavioural and on a neuro-anatomical level. On a behavioural level, we have discussed how the executive functions (working memory, strategy formation, planning, selective attention, and impulse control), and social cognition (theory of mind) tend to correlate with the degree to which a person will perceive internal versus external control. This control orientation, often expressed by the personality trait locus of control, is further suggested to be the product of motivated behaviour and of emotion regulation capacities which can be traced back to an infant's temperament. The ability early in life to selectively divert attention towards comforting, reinforcing stimuli, and away from disturbing ones, combined with repeated learning of stimulus-reinforcement associations, enables contingencies about recurring causal events in the world to be established. Establishing contingencies through rule-based reasoning (if… then) between one's own behaviour and the resulting outcome, allows an individual to gain a sense of control over the environment. This sense of control is apparent in behavioural outputs such as goal directed, and flexible behaviour.

On a neuro-anatomic level, we discussed the possible roles of three cortical regions. Within the prefrontal cortex, the dorsolateral cortex may be important in providing the cognitive skills necessary for these executive functions, while the ventromedial/orbitofrontal cortex and the anterior cingulate gyrus may provide the necessary link with social and emotional decision-making, which may be a key to understanding human individuality. The anterior cingulate gyrus was further discussed as the site where an attention network becomes localized and action-selection is monitored. Because of the limbic input at this same site, control perception could develop in response to the regulation of attention away from negative affective stimuli and towards positive affective stimuli. The child's innate emotional reactivity, along with his or her environmental experiences during which this selective attention mechanism has to operate, would contribute to the development of emotion regulation capacities and later locus of control.

Finally, a possible role of dopamine metabolism along three subcortical-cortical pathways was discussed. Perceiving internal control may be a function of cortical dopaminergic activation, promoting focused attention, action-monitoring, and approach behaviour, while perceiving external control is more likely the result of diminished action regulation and heightened arousal, orienting the individual towards novel, often superfluous, information.

Individual differences in locus of control orientations may further arise through differences in relative left hemisphere (ventral corticolimbic) versus right hemisphere (dorsal corticolimbic) activation, where left tonic activation is more associated with an internal locus of control, and right phasic cortical activation is more associated with an external locus of control. These differences in activation patterns may be the result of (1) differences in the extent of cortical dopamine modulation, (2) differences in social cognition or executive function proficiencies, (3) differences in motivation, and (4) differences in the development of a selective attention mechanism in the anterior cingulate gyrus to regulate emotions in early childhood. It is suggested that a person highly reactive to negative affect, and with more right hemisphere involvement and poor action regulation has more chance of developing poor emotion regulation capacities. If this is not moderated by cognitive executive or social skills, an external locus of control is more likely to result.

The degree to which internal (self-regulatory) control dominates over external (perception-action) control of behaviour will depend on the relative activation of cortical neural networks. This may vary between as well as within individuals, depending on the current situation, personal tendencies, and the history of subjective experiences.

As a final note, we will address some ecological implications of locus of control. We have so far described an internal locus of control as a characteristic of "healthy" personality, and that an internal locus of control is associated with well-being and successful behaviour and is generally viewed as a desirable trait. Given that the locus of control, like most personality traits, may be partly heritable (Miller & Rose, 1982; Pederson et al., 1989), and that psychometrically, the construct shows much intra-individual differences, one could ask what the evolutionary pressure may have been to keep an external locus of control in the population. If an internal locus of control had been universally advantageous, there would have been such strong selection for very high levels of this trait that genetic variation would have been exhausted. The fact that such variation remains up till today suggests that, under some circumstances, an external locus of control may also be adaptive and associated with a net gain in terms of its fitness benefits and its costs. In other word, we are faced with the question as to what the countervailing advantage of having an external locus of control might have been throughout our evolutionary past. Before attempting to formulate some possible advantages of an external locus of control, we point out that it is likely that directional selection already pushed the human species towards a more internal locus of control. Compared to other primates, humans have far more control perception, to the point that we may at times even fool ourselves with an illusion of control (Wegner, 2002). A possible reason for the weakening in directional selection and the continued existence of intra-individual differences in locus of control is that, with the rise of new technology, selection pressures today are not as strong as they were in ancestral times. As a result, variation is currently not narrowed down. This reasoning holds for people with a physical as well as a mental handicap who can survive and have children given the current social policies and medical care. Similarly, individuals with an extreme external locus of control who also suffer from learned helplessness or major depressive symptoms would have been weeded out in ancestral times, yet are functional today.

However, these two arguments above do not preclude the proposition that both internal and external locus of control may each have had strategic advantages in different situations, so that the intra-individual variation is the result of balancing selection. A first difference between internals and externals which may reflect an adaptive difference between the two phenotypes can be noted in group dynamics. Internals tend to be born leaders, while externals are followers. From evolutionary game theory it follows that, if a population has too many leaders, there may be an advantage to being a follower (and vice versa). Hence the roles they play in groups make them mutually dependent on each other and make organized division of labour possible. Second, from the studies mentioned earlier comparing the attention systems of internals and externals, it is apparent that externals are more easily aroused, while internals are much better at focusing their attention. Therefore, in ancestral times, individuals with an internal locus of control may have been more focused and goal-oriented, while individuals with an external locus of control may have been more easily startled, giving them an advantage in times of unexpected danger. Nevertheless, in current times the apparent advantages of an external locus of control fade in comparison with the perceived advantages of an internal locus of control. Much of the literature on the locus of control focuses on the positive behavioural outcomes associated with internality. This literature has generated a multitude of findings showing the advantage of an internal locus of control in the domain of achievements. However, how locus of control relates to other domain, such as creativity, musical abilities, or the Arts, still remains an open question. It is not unlikely that, with their more global perception and their task perseveration, externally oriented people may prove to be more artistically inclined and show superior creative abilities in these domains. Unfortunately, in a society which especially values achievement, these abilities are less rewarded, adding to the general finding that positive outcomes are usually only associated with an internal locus of control. However, just as extreme externality hampers human functioning due to the psychological inflictions often associated with it, extreme internality may be equally impeding, leading to illusions of control, grandeur, self deception, and hubris.

As is the case with most personality variables, the locus of control tends to show a normal, bell-shaped distribution. This reflects the underlying normal fluctuations in a trait which may have been selected on basis of its adaptive values. The fact that most people show an intermediate locus of control may not be incidental. These people tend to be more open to social support offered by others (Declerck et al., 2002), a finding which may perhaps account for why neither an extreme external or extreme internal locus of control is socially desirable. Clearly, the questions pertaining to the context-dependent advantages of a particular locus of control orientation, as well as the types of adaptive behaviours associated with an intermediate locus of control, deserve further investigation.

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