The Anticipating Mind

The making of thoughts, feelings and behavior

Peter F. Greve

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The bear on the cover seems curious about something in the environment. Being curious is important for animals and human beings alike because it enables detecting remote dangers and opportunities, which improves the chances of survival substantially. The picture is from the album 'The nights of the bear' by the wildlife photographer Stefan Unterthiner (Ylaios Edizioni di Paolo Ciambi, Italy 2009).

Background information about the book can be found in www.bodyandmindsystem.nl
(If your browser cannot find the site, try another browser)

For Minke

PREFACE

At some point during my years as a student of experimental physics I wanted to understand how my mental apparatus worked. I looked in the relevant literature for an explanation, but to my surprise I did not find a general theory that could explain the main neurological, behavioral and philosophical aspects of the mind in a coherent way. Moreover, I discovered that the investigations of the mind carried out in different scientific disciplines – such as artificial intelligence, ethology, the neurosciences, philosophy, psychiatry and psychology – were poorly related. A more positive result was that it made me think of an alternative approach, which I decided to work it out. Fortunately, literature about the mind is abundant; this enabled me to get acquainted with many of the aspects of the mind that have been studied. Based on this information and on what I observed in my own mind I developed working hypotheses about a diversity of mental phenomena in terms of their underlying processes. Later on, I forged these hypotheses into a theory about the mind, or more precisely: a theory about the processes that constitute the mind. For me, this was an adequate answer to my question.

The idea that this theory could also be useful for other people made me write this book. Its main message is that it is possible to develop a comprehensive theory about animal and human minds that is both multidisciplinary and coherent, and to describe this theory in a way that makes it accessible to a non-specialist audience. I believe that the book can be of interest for scientists because it offers a cohesive view of many aspects of the mind and captures elusive mental issues – such as consciousness, creativity and intuition – in explicit formulations. More in general, I hope that people who are, like me, curious about the mind will find this an interesting book because it provides new angles for dealing with psychological and philosophical issues.

Peter F. Greve

INTRODUCTION

> "Briony […] raised one hand and flexed its fingers and wondered, as she had sometimes before, how this thing, this machine for gripping, this fleshy spider on the end of her arm, came to be hers, entirely at her command. Or did it have some little life of its own? She bent her finger and straightened it. The mystery was in the instant before it moved, the dividing moment between not moving and moving, when her intention took effect. […] She brought her forefinger closer to her face and stared at it, urging it to move. It remained still because she was pretending, she was not entirely serious, and because willing it to move, or being about to move it, was not the same as actually moving it. And when she did crook it finally, the action seemed to start in the finger itself, not in some part of her mind. When did it know to move, when did she know to move it?" [1]

The mind is of intimidating complexity, so it is not surprising that relatively little is understood of the way it works. Questions that are yet unanswered include: how do thoughts lead to behavior, what are the mental mechanisms that underlie intuition, how are gut feeling, reason and consciousness related and why must we sleep? Here, a perspective will be proposed from which such questions can be addressed in a systematic way.

The book has three parts. Part one develops a process model of the mind, draws conceptual conclusions from it and explains various aspects of behavior and mental activity. Part two expands the model by proposing a generative mechanism that underlies the creative nature of mental processing; moreover, the generative mechanism is related to a method for describing mental processes mathematically. Part three explores the mental processing that is typical of the human mind, making use of the process model developed in the other two parts. The epilogue describes a possible follow-up project. Together, the model, the explanations, the conceptual conclusions and the exploration of the human mind constitute an elaborate working hypothesis about mental processing. Because the process of anticipation plays a key role in it, I call it the 'AM theory' in which AM stands for anticipating mind.

In the course of time, many theories about the mind have been developed. Some of them seek direct correlations between behavior and the neurophysiology of the brain [2]. Figure 1A symbolically sketches this approach. Other theories are restricted to only one – or a few – aspects of the mind [3], which is sketched in figure 1B. The third approach is sketched in figure 1C. It consists of proposing an array of separate ideas about the mind without bringing them together in a coherent theory [4]. The approach proposed here – sketched in figure 1D –

consists of developing a hierarchical model of the mental processes that underlie behavior. The rectangular structure in the figure represents this hierarchy; it is a small-scale copy of the overview in Appendix 7 of the hierarchy proposed in the book.

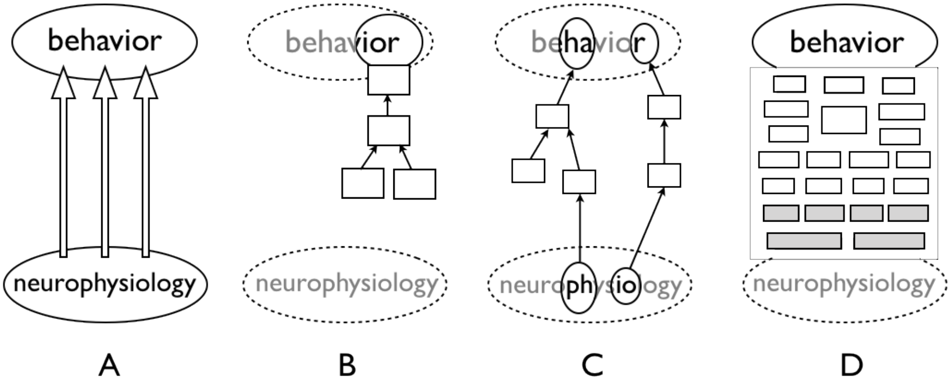

Figure 1 Four ways to explain the mind. A: Seeking direct correlations between the neurophysiology of the brain and behavior. B: Zooming in on only one or a few aspects of the mind and some of the mental processes (represented by rectangles) involved. C: Describing separate ideas about the mind and the underlying neural processes without integrating them into a coherent theory. D: The approach followed in this book: addressing the hierarchy of the mental processing underlying behavior. The rectangles in the box represent the mental processes operating at different levels within the hierarchy. The bottom-level processes (grey fields) are to be explained from their neurophysiological underpinning.

The use of faint letters in figure 1D of the word 'neurophysiology' symbolizes that this book does not discuss the neurophysiological foundation of mental processing. The main reason for this is that before this foundation can be addressed, first the low-level mental processes that depend directly on neurophysiological processes must have been identified[1]. This requires, in its turn, an adequate understanding of

[1] As an illustration of this way of working, imagine you want to find out how an old-fashioned TV set works. An obvious approach is to open the apparatus and to analyze its parts and their interconnections. Everyone who has done this has probably experienced – like me – that soon the mind becomes dazzled by the sheer complexity of the wiring and the great number of parts. A far more effective approach is to start with consulting a textbook that explains the elementary functions in the apparatus. Armed with this knowledge, one can start a more goal-directed investigation in which one looks for, e.g., the antenna amplifier, the power supply and the high voltage module without being distracted by details that are of secondary importance. Similarly, when trying to understand something as complex as the mind it is efficient to start with gaining basic insight into its main functions instead of investigating the neural wiring and components.

the whole hierarchy of mental processes, which is precisely what this book is about.

In particular, the following theories about the mind are relevant to the discussion in this book:

- The 'radical constructivist' theory proposed by the psychologist, physicist and philosopher Ernst von Glasersfeld [5]. Its development was inspired by the study of the mental development of children by the psychologist Jean Piaget [6] and the hypotheses about the generative nature of the mind proposed by the biologists Humberto Maturana and Francisco Varela [7]. Although Von Glasersfeld took a different route in his exploration of the mind, the conceptual conclusions he arrived at are similar to those of the AM theory.
- The 'interactivist model of representation', a pragmatic theory proposed by the social scientist Donald Campbell and worked out by the theoretical psychologist and philosopher Mark Bickhard [8]. Like the AM theory, it is a process-based rather than substance-oriented approach but it has a less broad scope and it discusses mental processes in a less detailed way.
- The 'Three Worlds' theory developed by the philosopher Karl Popper and the neurophysiologist John Eccles [9]. The conceptual conclusions this theory arrives at are diametrically opposed to the conclusions drawn here. This difference will be discussed in part three of the book.
- The 'hierarchical predictive coding' theory, developed by the neuroscientist Karl Friston and his co-workers, proposes a method for describing mental processes in terms of probability mathematics [10]. This makes it possible to develop quantitative hypotheses about mental issues. In part two of the book, the relationship between this approach and the AM theory will be discussed.

An aspect that sets the approach followed in this book apart from most of the approaches mentioned above is that it pays due attention to biological aspects such as evolution, ontogenetic development and what mental processing contributes to survival. Not doing so means that important opportunities are missed. For instance, without considering the biological basis of the mind, it is hard to obtain a well-founded insight into what human minds share with animal minds or to explain the interaction between the body and the mind in a convincing way. Moreover, since the process of evolution shaped both the brain and the body, insight into the evolutionary backgrounds of mental processing provides a key to the understanding of important properties of the mind.

Acknowledgments

First of all, I wish to thank Minke, my wife. She helped me keep my feet on the ground, granted me the workspace I needed for studying and writing, and reviewed an endless series of drafts. And I look back with great pleasure on the many in-depth discussions I had with her about many of the topics addressed in this book. Furthermore, I owe a lot to my daughter Mirte because of her useful advice about how to address an audience.

I feel very grateful to the scientists who were so kind as to review my writings at various stages of the project. My first reviewer was the cognitive scientist Marieke Rohde; her remarks were critical but they helped me to move forward. To my great relief, my next reviewer, the neuroscientist Ole Jensen, saw no conflict between the gist of my proposal and neuroscientific evidence. At later stages of the project, I was so fortunate as to receive elaborate reviews from three neuroscientists – Germund Hesslow, Karl Friston and Wim van de Grind –, the mathematician Arie de Bruin, the philosopher Alexander Riegler, the technician and philosopher Torbjörn Skytt, the artificial intelligence scientist – with an interest in biology and linguistics – Julian Gonggrijp and the biologist Jelle Boonekamp. Their comments contributed considerably to the content of the book. The positive attitude that, in particular, Karl Friston and Julian Gonggrijp showed towards my project prevented me from giving up.

I wish to thank four heads of department for welcoming me in one of their workgroups: the psychologist Anna Bosman, the philosopher Marc Slors, the sociologist Harry Kunneman and the theoretical biologist Diedel Kornet. With the artists of 'Diedel's circus' – Diedel Kornet, Arie de Bruin, Julian Gonggrijp, Rob Nagtzaam and Esther Wieringa – I had many inspiring discussions. Moreover, Diedel Kornet gave me invaluable support during my first attempt to publish in a scientific journal.

Furthermore, I am grateful for the information and helpful advice that I received from the psychologist Chris Frith, the neuroscientist Maarten Demeyer and the biologist William Hodos. I cordially thank Paul Cornelisse, Manja Geijsel, Wessel Henny, Jaap Jaspers, Marleen Kornet, Pim Korving, Christopher Macann, David Rosenthal, Tineke Royle, Kirstine Sturkenboom, Jan Kees van der Veen, Hans Verhoeven, René Verwaaijen, Heleen van der Vlugt and Huub Vroomen for their useful remarks. And I am indebted to the psychologists Harold Bekkering and Mark Bickhard for their indispensable assistance in the process of publishing a paper in 'New Ideas in Psychology' [11].

PART ONE: A MODEL OF MENTAL PROCESSING

I.1 Introduction

In this book, it is assumed that – besides its regulatory functions – the primary task of the brain is to prepare and guide actions that improve the chances of survival and procreation, and other aspects of fitness[2]. The mind is defined here as the collection of processes that enable the brain to perform this task.

This part of the book develops a model of mental processing. Not only does it describe what animal and human minds have in common but it also indicates the capabilities that make the human mind unique.

[2] Fitness is the genetic contribution of an individual to the next generation's gene pool relative to the average for the population. It is usually measured by the number of offspring or close kin that survive to reproductive age [12]. In this book, an activity is called adequate if it improves – or could improve – fitness

I.2 Anticipation

During evolution, different biological systems for movement control evolved that enable organisms to perform adequate actions. At some point in this evolution, neural networks became important elements of these systems. From these networks, the current anticipating networks called brains evolved.

Discussing this evolutionary background of anticipation is necessary because in this book, only proposals about mental mechanisms that have a biologically credible history of origin are considered acceptable. In this section, those early systems will be discussed that introduced basic mechanisms that are still active in today's anticipating networks. The goal of this way of working is to make it plausible that the mental functions and processes proposed in the book are not inventions of an engineer but are – or at least could be – the outcome of an evolution, a non-teleological – 'blind' – process of adaptive specialization and competition over limited resources such as food and living space. However, because this section is not about the main theme of the book – anticipation –, its discussions are not detailed, the quantitative aspects of the increase of the complexity of neural networks during evolution are not addressed and only some of the presumably broad fitness benefits of the early neural networks discussed are briefly mentioned.

There is no fossil evidence available of the way the early neural networks operated, so the networks discussed here are inevitably hypothetical.

I.2.1 Before anticipation appeared

I.2.1.1 Sensorimotor mechanisms, reflexes and associative response

<u>Sensorimotor mechanisms</u>

Before neurons evolved, molecular sensorimotor mechanisms enabled organisms to respond adequately to direct contact with the immediate surroundings. For example, bacteria can find their way towards a more nutritious area by detecting and evaluating the differences between the previous and present concentrations of nutrient they sample from the surrounding fluid [13]. Note that for comparing the present situation with an earlier situation it is necessary that information about the earlier experience is temporarily stored in (molecular) working memory.

Neural connections and neural networks

Sensors evolved that facilitate the detection of cues located at some distance, and neurons developed for connecting these sensors with the action organs. These developments provided organisms with the capability to respond to stimuli from an area of the environment that is substantially larger than the immediate surroundings, which reduced the chance of falling victim to a predator and improved the ability to detect opportunities in the environment.

From the neural connections, neural networks evolved that can process the sensory signals in a way that improves the usefulness of these signals. For instance, in some species, there is a neural network behind the eye that enhances the contrast in the visual image by means of 'recurrent inhibition', which is a specific type of signal interaction between neighboring neurons. Another example is the development of neural networks that function as working memory that facilitates comparing the present situation with a previous one, which is indispensable for the optimization of the adequacy of the behavior of the organism. This neural working memory probably evolved from the molecular working memory of bacteria discussed above.

An interesting aspect of these evolutionary developments is that it seems by no means likely that they should take place. In general, bacteria can evolve a lot faster than the more complicated organisms equipped with sophisticated sensors and neural networks because the shorter intervals between their generations give them a greater potential to quickly adapt to environmental changes. Moreover, developing and maintaining sensors and neural networks require considerable investments in terms of energy and the allocation of resources such as building materials. The fact that these specialized neural networks evolved indicates that their fitness benefits must have exceeded their costs.

Reflexes

I hypothesize that next in the evolution of neural networks, reflex units – consisting of a sensor, a neural network and an action organ – evolved. Such a unit produces a prompt and unconditional response to a salient sensory stimulus according to a more or less fixed scheme (figure 2). Examples of a salient stimulus include a sharp sound, a penetrating smell and a sudden movement in the peripheral field of view. A reflexive response that consists of an action is called an 'action reflex' here.

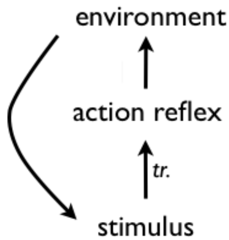

Figure 2 The action reflex. A salient stimulus from the environment triggers – 'tr.' – an action according to a fixed scheme. As a result, the organism interacts with the environment.

Initially in ontogenetic development, the characteristics of a reflex unit are determined by genetic predispositions. The unit may retain these characteristics throughout the life of the organism, but in some cases adaptation occurs. In particular, the repeated processing of certain sensory signals may lead to an adaptation of the network so that the next time, the response to similar signals will be slightly different. A series of such changes may even add up to a considerable alteration of the properties of the network. Take, for example, an animal born with the reflex of starting a search for food when it smells a certain odor. If it repeatedly experiences that, actually, in spite of the smell no food is present, then mental adaptation decreases the strength of the search reflex and eventually may make the animal ignore the stimulus completely [14].

I hypothesize that from the action reflex, the 'conditional reflex' and the 'associative response' evolved. A major difference between them is that the first is genetically determined whereas the second is a learned response.

Typical of the conditional reflex is that there are (at least) two possible fixed options for the response. Which one is chosen depends on the circumstances, as symbolically sketched in figure 3. For instance, a specific sound combined with a specific smell triggers a hiding response, but when another odor is noticed, the sound triggers explorative behavior.

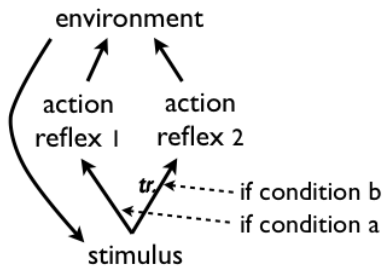

Figure 3 The conditional reflex. Here, there are two options for action reflex; which one is executed depends on the circumstances.

The associative response – sketched in figure 4 – has a learning phase and an execution phase. The learning activity consists of forming an association between an action reflex and the (almost) synchronous perception of a second stimulus. The association is established after this combination of events has repeatedly been noticed. Storing it in working memory sets the stage for the execution phase: as soon as the animal perceives something similar to the stored second stimulus, this triggers the execution of the stored action. For example, in the 'Pavlov response' of a dog, the action reflex consists of the animal's salivation as a response to smelling food and the second stimulus consists of, e.g., a specific sound produced by the person who is training the animal. After having repeatedly experienced the synchronous occurrence of these events, the animal salivates whenever it hears the sound.

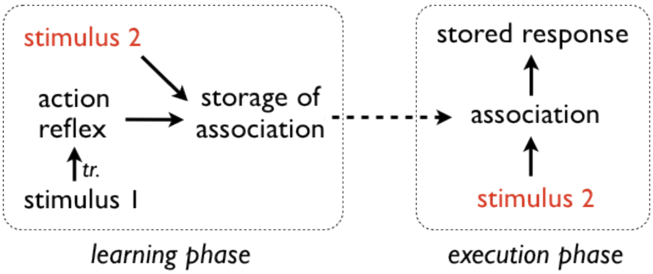

Figure 4 The associative response. In the learning phase, the neural network notices and stores the repeated coincidence of a reflex response to a stimulus – 'stimulus 1' – and a specific sensory experience: 'stimulus 2'. In the execution phase, a sensory stimulus similar to the stored one triggers the execution of a copy of the stored response.

<u>The internal reflex</u>

The arrival of a signal in a neural network may lead to a change of the processing conditions such as the adaptation of an activation threshold, the storage of information in working memory or making the network exert influence on another network. If this response of the network to a trigger signal is unconditional, it is called an 'internal reflex' here. The source of the trigger signal may be another neural network or a sensor that responds to a stimulus from the environment, as depicted in figure 5. Note that the latter stimulus may trigger both an internal reflex and an action reflex.

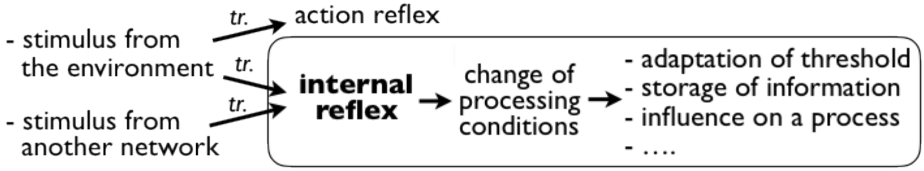

Figure 5 An internal reflex – triggered by a stimulus from the environment or from another neural network – changes the processing conditions in a network. This may initiate another process and/or facilitate a specific network response.

I.2.1.2 Using models of the environment

From solidification to OIM

I hypothesize that a decisive step in the evolution of neural networks was the development of neural networks that can draw – from sensory impressions – the (almost philosophical) conclusion that there must be an object in the environment that has a certain permanence and is worth noticing. The latter means that interaction with the object is likely to have a significant – detrimental or beneficial – effect.

In terms of neural processing, drawing this conclusion means that the neural network involved has constructed an internal model of the object. This means that this network creates a more or less stable entity from fleeting patterns of neural signals. This process is called 'solidification' here and what it produces is called a 'mental entity'. Note that the stability of a mental entity does not exclude that the underlying signal processing is dynamic. For instance, signals that repeatedly follow the same trajectory within a neural network may – together – produce a stable output (> II.2.1.3)[3].

The mental entity created by the network is called a model here if it is a best guess about something outside the brain that can be used for preparing adequate action. The above-mentioned model of an object is called an 'object concept' here. The next step in evolution was the development of neural networks that can construct and maintain a stable but adaptable assembly of object concepts that provides a guess about the immediate environment that can be used for action preparation. This elementary model of the environment is called the 'OIM' (Organic Immediate Model of the environment) here. In this name, the word 'immediate' not

[3] This internal reference provides a link to a section in the book where background information or a continuation of the discussion can be found. This information only serves to enrich the text at the reader's convenience, so reading it is not required for comprehension of the text. The '>' symbol indicates that the issue that was just discussed will be explained or further discussed in the indicated section, whereas the '<' symbol refers to an earlier section where the issue was discussed or introduced.

only means that the model concerns objects in the immediate environment but also that the model is immediately adapted to the changes in the environment that occur. The term 'organic' will be explained later on.

In this book, the brain is defined as a biological neural network that constructs a model of the environment and uses this model for generating predictions.

Importantly, the capacity to make predictions in the context of an OIM enables the brain to optimize its behavioral choices before an action is executed. The behavior orchestrated on this basis is called 'goal-directed' behavior here; it is the same as intentional behavior. The initiative for executing a goal-directed action is taken within the mind; this makes this kind of action fundamentally different from the reflex that is triggered by a stimulus from the environment.

OIM-based action preparation contributes significantly to the chances of survival and reproduction because it enables the animal to avoid dangerous situations, to make optimal use of the opportunities present in the environment and to move through the environment in an efficient way. For example, an animal that notices that a big rock lies ahead can plan a route around the obstacle. In figure 6, the option of OIM-based action has been added to the action reflex, the conditional reflex and the associative response.

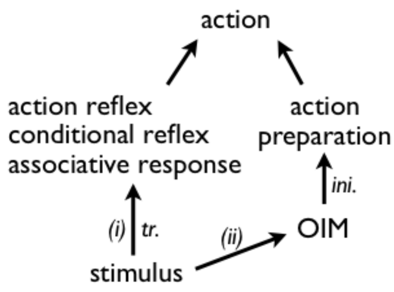

Figure 6 Two kinds of action: (i) A stimulus triggers an action reflex, conditional reflex or associative response. (ii) The mind constructs from sensory information an OIM and it prepares and initiates – *'ini.'* – goal-directed actions based on this model. Not shown here is that the OIM is updated by sensory signals in the specific way that will be described below.

Vigilant perception

Noticing objects in the environment is the result of a search for information in the environment, which is called 'vigilant perception' here. This search is performed by, e.g., scanning the surroundings with the eyes and/or the ears (> I.3.2.2). The mind initiates the search when it requires additional information. For example, seeing a big rock ahead raises the need to determine the height and width of the rock in order to be able to make an adequate planning for continuing the journey. Hence, vigilant perception is a goal-directed activity.

An important aspect of vigilant perception is that its goal is known at its start so that before it has been completed the mind gets the chance to generate an expectation about what the perception will deliver. This anticipation provides an opportunity for the mind to learn from the differences between what was expected to occur and the actual action results, which makes it possible to optimize the adequacy of the OIM and of the way this model is employed in an efficient and effective way. In this way, an ongoing experience-based process of improvement of the adequacy of the mind is achieved. The elementary neural networks that can only produce reflexes and associative responses – so are unable to perform vigilant perception – lack this capacity of continual improvement.

The fitness benefits of these features of OIM-based action preparation must have provided a significant driving force behind the development of increasingly more sophisticated brains. I hypothesize that the scope of the OIM grew during evolution from only containing information about the appearances of the objects in the environment to comprising other aspects that are important for survival – such as issues related to food and safety – as well. For instance, it is likely that many well-developed minds generate and maintain a map of escape routes and potential hiding places in the surroundings so that the animal can dash to a safe spot as soon as it detects danger.

The body self

Since the body is the direct environment of the brain, the OIM contains a model of it, which is called the 'body-self' here. The mind employs elements of it – about, e.g., the arms and the legs – when it prepares movements. I hypothesize that it also contains the following model of the effects of emotions.

The brain can communicate bidirectionally with the body by exchanging message particles like hormones via the bloodstream (> I.3.5.1). In this way, the brain can influence processes in the body, and the state of the body can influence the processes in the brain. Important for the discussion held here is that the concentrations of message particles in the blood may vary due to, e.g., a variation of the surrounding temperature, the time of the day, the intake of food, physical activity and/or the secretion of a hormone by an organ. If the mind notices – by way of association (< I.2.1.1) – that repeatedly a deviation of a certain particle concentration has a particular effect, then it stores this correlation in the form of a model within the body-self. This particular sub-model enables the mind to deal effectively with emotions. For instance, it facilitates generating the insight that the sad feeling that one is experiencing may be due to fatigue or illness.