Self-attachment: A holistic approach to Computational Psychiatry

Abbas Edalat

Abstract There has been increasing evidence to suggest that the root cause of much mental illness lies in a sub-optimal capacity for affect regulation. Cognition and emotion are intricately linked and cognitive deficits, which are characteristic of many psychiatric conditions, are often driven by affect dysregulation, which itself can usually be traced back to sub-optimal childhood development. This view is supported by Attachment Theory, a scientific paradigm in developmental psychology, that classifies the type of relationship a child has with a primary care-giver to one of four types of insecure or secure attachments. Individuals with insecure attachment in their childhoods are prone to a variety of mental illness, whereas a secure attachment in childhood provides a secure base in life. We therefore propose, based on previous work, a holistic approach to Computational Psychiatry, which is informed by the development of the brain during infancy in social interaction with its primary care-givers. We identify the protocols governing the interaction of a securely attached child with its primary care-givers that produce the capacity for affect regulation in the child. We contend that these protocols can be self-administered to construct, by neuroplasticity and long term potentiation, new "optimal" neural pathways in the brains of adults with insecure attachment history. This procedure is called Self-attachment and aims to help individuals create their own attachment objects which has many parallels with Winnicott's notion of transitional object, Bowlby's comfort objects, Kohut's empathetic self-object as well as religion as an attachment object. We describe some mathematical models for Self-attachment: a game-theoretic model, a model based on the notion of a strong pattern in an energy based associative neural network and several neural models of the human brain.

Abbas Edalat
Algorithmic Human Development Group, Department of Computing, Imperial College London
e-mail: a.edalat@ic.ac.uk
Published as: A. Edalat. Self-attachment: A holistic approach to computational psychiatry.
In Amy Cochran Peter Erdi, Basabdatta Sen Bhattacharya, editor, Computational Neurology and Psychiatry, Springer series of Bio/Neuroinformatics. Springer, February 2017.

1 Introduction

In the past few years, Computational Psychiatry has grown as an emergent subject following remarkable advances in Computational Neuroscience in general and in Reinforcement Learning in particular. Work in Computational Psychiatry so far has focused on computational models to explicate cognitive impairment and deficits, including sub-optimal decision making, that are are ubiquitous in all varieties of mental disorder. This has led to a number of interesting results which use Reinforcement Learning or Game Theory to model depression, borderline personality disorder and other psychiatric illnesses [71, 53]. The underlying approach is reductionist and consists of constructing models that describe a given form of normal or healthy decision making or behaviour which are then modified to understand the abnormal or impaired form of the same process in mental illness. It is hoped that these models can help us better understand mental illness and can aid us in developing treatments and in particular pharmacological interventions for psychiatric diseases.

In this article, we propose a holistic approach to Computational Psychiatry, called Self-attachment that was first introduced in [30] and [31], and focuses on early attachment insecurities in childhood. There has been increasing evidence over the past decades to show that early attachment experiences of infants with their primary care-givers play a crucial role in the development of their capacity for affect regulation, which is vital for enhancing resilience in the face of stress in life and averting mental illness. It is now believed that early negative attachment interactions have an adverse impact on the development of this capacity in children, making them vulnerable to psychological disorders later in life [84, 70]. This view has been supported by Attachment Theory, a scientific paradigm in developmental psychology introduced by John Bowlby in 1960's [15], which has also had an impact on psychotherapy in the past few decades [14]. This will be described in detail in the next section.

Whereas attachment insecurities create vulnerability to mental illness, a number of experiments–using a technique called "security priming"–have been able to artificially activate mental representations of supportive attachment figures and thereby improve the mental health of individuals suffering from various mental disorders [70]. Individuals are also capable of using a constructive marriage or a therapeutic framework to "earn their secure attachment" [70]. In particular, in schema therapy "limited reparenting" is used to redress early maladaptive schemas in the parent-child interactions, help the individual find experiences missed in childhood, and establish a secure attachment through the therapist [102].

Many studies in the past two decades have provided compelling evidence that for thousands of years human beings have used religion to mirror a caring parent as an "attachment object" to redress their attachment insecurities and regulate their emotions, what has been called the "compensatory pathway" to religious practice [47]. Attachment objects were originally studied in the context of children's development by Donald Winnicott under the name transitional objects [98] and were later used as cloth-covered surrogate dummy mothers by Harry Harlow in his experiments with infant monkeys [48]. Bowlby referred to them as "substitute objects" or "attach-

ment figures" that acted as a substitute for the mother [15]. It has also been argued that religious practice in human beings resembles the use of transitional objects in children's development as described by Donald Winnicott [68].

In addition, functional Magnetic Resonance Imaging (fMRI) studies since 2000 have confirmed that the activation of the dopaminergic reward systems of the brain is a common feature of romantic love, maternal love and religious praying, all of which create an affectional bond. From these findings, we infer that creating an affectional bond, be it in the context of parental love, romantic love or religious practice, provides a basis for attachment interactions that in turn are aimed at emotion self-regulation [6, 7, 83].

Self-attachment therapy, as described in [31], proposes that early attachment insecurities of adults who have become victims of psychiatric disorders can be addressed and tackled with self-administered protocols that emulate secure child-parent attachment interactions by mental representation. The individual pro-actively takes up the role of a nurturing parent for reparenting a mental representation of the "inner child", the emotionally damaged child that the individual was in early life. For this purpose, an internal affectional bond is created by the "adult self" with the inner child. The next stage is based on two fundamental paradigms in neuroscience: (i) neuroplasticity, i.e., our brain's capacity to reorganise its neural circuits by forming new neural connections throughout life, and (ii) long term potentiation, i.e., a persistent strengthening of synapses based on recent and repeated patterns of activity [77, chapter 24]. The goal of Self-attachment is to produce in a systematic and repeated way virtual secure attachment experiences in the individual that by neuroplasticity and long term potentiation would create neural circuits that provide a sense of secure attachment in the individual. With this sense of secure attachment the individual then revisits traumatic experiences in connection with the mental image of the inner child in order to reprocess these episodes with a supporting parent represented by the adult self of the individual. The goal of the exercise is to help the individuals to create their own secure attachment objects that can support them in self-regulating their emotions.

In [31], a number of promising case studies of practicing Self-attachment were reported. In these case studies, individuals with chronic depression and anxiety, resistant to various forms of previous psychotherapy, had significant clinical improvement in their symptoms following the practice of Self-attachment. We previously proposed the use of virtual reality as an alternative to imagery techniques for simulating the interaction of the "inner child" with the "adult self" [30]. In the two related virtual reality experiments reported in [35, 36], individuals with either excess self-criticism or with depression embodied a virtual child and then a virtual adult to receive self-compassion, which is one of the first interventions in Self-attachment. In both experiments, the embodied interactions between the virtual child and the virtual adult resulted in an improvement in their self-criticising or depressive symptoms. These compassionate interactions can be regarded as interactions between the "inner child" and the "adult self", even though the individuals had not made a conscious effort to perceive the interactions in this way. We therefore submit that

the above virtual reality experiments have provided additional proof of concept for Self-attachment.

The rest of this article is organised as follows. In Section 2, we briefly review the basic tenets of attachment theory, the neurobiology of secure and insecure attachment, the vulnerability to mental illness caused by insecure attachment and the impact of attachment theory on psychotherapy. In Section 3, we describe the role of attachment objects for emotion self-regulation in ethology, in children's development and in religious practice. In Section 4, we explain how fMRI experiments on romantic love, maternal love and religious prayers since 2000 indicate a common overarching paradigm for rewarding affectional bonds in these different contexts. In Section 5, first the nature of Self-attachment intervention is explained and then the Self-attachment protocol is outlined. In Sections 6 and 7, a game-theoretic model for Self-attachment and a model based on strong patterns that are learned deeply in an associative artificial neural network are presented. Finally, in Section 8, we describe several neural models of the human brain for Self-attachment.

2 Attachment Theory

Attachment Theory was first formulated by John Bowlby [15], based on his studies of separation anxiety of infants from their mothers, and was later developed along with Mary Ainsworth. In the past decades, it has been regarded as a main scientific paradigm in developmental psychology [19]. According to Bowlby, human beings, as well as higher primates, are born with an innate tendency to seek proximity to their primary care-givers to feel secure and safe in particular in times of need and stress. He argued that if the infant's needs for attachment are met by a sensitive parent capable of quick and appropriate response when the infant is in distress, then a stable and secure sense of self is developed in the infant which leads to positive association with the self and others in life. However, when the primary care-giver is unreliable, insensitive and thus unable to respond quickly and appropriately to the needs of the infant, an insecure sense of self and negative models of self and others are developed in the infant which would be the source of later emotional problems.

Bowlby [14] proposed that the type of emotional attachment children develop with their primary caregivers will become the foundation of their "internal working model", a cognitive framework with which the child and later the adult interprets the social world and predicts the outcome of her/his behaviour in view of past memory. Thus, through the internal working model, the early attachment types of children have a great impact on their future emotional and personality developments as adults engaging in social and intimate relationships.

In its present form, Attachment Theory classifies the quality and dynamics of the relationship of a child with his/her parent into four types of attachment: secure attachment and three kinds of insecure attachments (avoidant, anxious/ambivalent, and disorganised) [67]. It is proposed and vindicated by longitudinal studies that attachment types strongly impact on the emotional, cognitive and social develop-

ment of the child into adulthood by determining the individuals working model of relationships [87].

The theory has been corroborated by the Strange Situation experiment [2] developed in the 1970s by Mary Ainsworth who was inspired by Harry Harlow's experiments with monkeys. The Strange Situation experiment has become the standard measure of eliciting attachment in infants [67]. This procedure, involving a mother, her one year old toddler, and a stranger in an unfamiliar room, has been repeated across many different cultures, with results indicating similarities but also differences in the distribution of attachment types among the toddlers in different societies [93, 94].

It is hypothesised that the particular type of attachment developed in a child depends crucially on the kind of response by the parent to the child's emotional needs, which is repeated over and over again during the formative stage of the infants development. The primary care-giver of a securely attached child responds quickly and appropriately to the distress signals of the child and in due course the child learns to use the primary care-giver both as a safe haven and as a secure base in order to explore the world, while feeling assured that whenever a stress situation arises the primary care-giver is available to provide support and reassurance. The primary care-givers of the insecurely attached children, however, often respond to the emotional needs of the child by rejection, in the case of avoidant insecure child, or by inconsistent behaviour, in the case of anxious insecure child, or by frightening the child, in the case of a disorganised insecure child [95, p. 19–24].

2.1 Regulation theory: Neurobiology of secure attachment

John Bowlby's Attachment theory was influenced by a number of disciplines including control theory and cybernetics. In fact, Attachment theory has been considered as a regulation theory in particular in the work of Allan Schore in the past two decades [85]. His work explains how secure attachment leads to the capacity for self-regulation of emotions and how this is mapped in the infant's developing brain. We will briefly explain the essential components of Schore's regulation theory.

Schore quotes the following assertion from developmental psychoanalysis by Robert Emde [34]:

> It is the emotional availability of the caregiver in intimacy which seems to be the most central growth-promoting feature of the early rearing experience.

Visual experience is thought to play an important role in the emotional development of the infant and its emotional attachment to the parent in the first, so-called practicing, year. Through intense mutual gaze, the infant-parent dyad is established, creating a framework for transmission of mutual influence and inter-communication. The parent is attuned to and resonates with the internal state of the infant at rest and is able to contingently fine tune her affective stimulation with the infant's dynamically activated, deactivated or hyperactivated state. The infant's right hemisphere is

intensely involved in the visual interactions with the mother and is used as a template for imprinting what it receives from the mother's emotion-regulatory right cortex. This leads to entrenched circuits in the infant's right brain that reflect the mother's right brain activities and will be used in turn to regulate the infant's emotions. The mutual and intense gaze, facial expressions, mirroring and resonance between the infant and the mother release endogenous opiates inducing pleasure and release of dopamine from the ventral tegmental area resulting in dopaminergic-driven arousal and dopamine-mediated elation. High levels of dopamine secretion results in a rapid growth rate of the infant's brain by accelerating the transcription of genes and DNA synthesis and by regulating dendritic growth [84, p. 14].

The affective homeostasis in the child-parent dyad is used by the primary care-giver to minimise the child's negative affects, maximise its positive affects and moderate its arousal level. This drive for attunement and homeostasis with the child is particularly paramount in the first year of life.

It is proposed, based on a large volume of research in neuroscience, that the resulting emotional regulation in the child is rooted in the development of several brain regions, in particular the Orbital Frontal Cortex (OFC) which as part of the prefrontal cortex is densely connected to the limbic system and thus acts as its "executive director". The orbitofrontal cortex develops on the basis of the type of interaction infants have with their primary care-givers and is critically involved in attachment processes that occur during the first two years of life [84, p. 14]. The optimal growth of the OFC in the securely attached toddler allows delayed response based on stored representation rather than immediate information in the environment. The child develops a mental image or a schema of the parent and a primitive capacity for self-reflection which allow the child to withstand short and temporary absence of the parent. The infant thus acquires a learning brain able to explore the world.

Schore summarises the significance of these early infant-mother interactions [84, p. 12]:

> This mutual regulatory system is adaptive in that it allows for the arousal level of the child's developing nervous system to be rapidly recalibrated against the reference standard of the mother's.

In the second, so-called socialising year of life, the child is able to walk and run, and so a key role of the primary care-giver is to restrain the child from dangerous or anti-social behaviour. This for the first time results in a break-up in the homeostasis between the child and the primary care-giver and thereby to the painful experience of shame by the child. By being sensitive, responsive, emotionally approachable and staying with the child, the parent of a securely attached child is able to re-enter into synchrony and mutual gaze with the child. It is in the repeated process of misattunement and reattunement with the primary care-giver that the child gradually learns that the break-up of homoeostasis with the parent can always be restored. The child and the parent then develop the capacity to move from positive to negative and back to positive affect and the child learns that negative affects can be endured. By staying in with the child the "good enough" parent [97], a notion popularised by the

British psychologist and paediatrician Donald Winnicott, allows the repair of the misattunement in the child-parent dyad.

Schore evaluates the maturation of the infant's brain as a result of these disruption-repair transactions between the infant and the mother as follows [84, p. 21]:

> These experiences trigger specific psychobiological patterns of hormones and neurotransmitters, and the resultant biochemical alterations of the brain chemistry influence the experience-dependent final maturation of the orbitofrontal cortex.

In this way, the child's brain becomes focused on exploring the world: in the words of Julian Ford, a "learning brain" develops [40], a concept that fits with the idea of "knowledge instinct" [76]. The OFC is also involved in internal regulation of states by its connections to the hypothalamus, which allows cortical containment of the autonomic sympathetic and parasympathetic somatic reactions induced by emotions [84].

2.2 Neurobiology of insecure attachment

The development of a securely attached child should be compared with that of insecure attached children. Here, we will briefly explain the situation for the avoidant insecure attachment, which can show the discrepancy in acquiring a capacity for emotional regulation [84, p. 27-28]. In contrast to the parent of a securely attached child, the parent of an avoidant insecure child expresses low levels of affection and warmth, is averse to physical intimacy and actively blocks proximity seeking approaches of the child. In reaction to a long history of dealing with such a primary care-giver, the avoidant insecure child shows no interest in engaging with an adult who tries to interact with him/her and exhibits little interest to get close to the adult. The normal process of attachment bonding is severely disrupted, which leads to failure of the regulatory mechanism and disturbance in the limbic activity and hypothalamic dysfunction. It is suggested that this negative attitude reflects suppressed anger in the infant because of past frustration in attempts to seek proximity with the primary care-giver. A psychobiological disequilibrium based on dysregulated brain chemistry is developed when the primary care-giver does not regularly engage in repairing misattunement to establish homoeostasis. Negative social interactions in the critical early years of development lead to permanent change in opiate, dopamine, noradrenaline and serotonin receptors. The primary caregiver's failure to engage quickly and appropriately in repairing the homoeostasis disruption traumatises the infant and results in defects in the development of the OFC and in biochemical dysregulation and toxic brain chemistry of the infant. In this way, the child's main focus will be how to avoid further trauma: in the words of Julian Ford, a "survival brain" develops [40].

It is thought that in avoidant insecure attachment the sympathetic nervous system, in anxious insecure attachment the parasympathetic nervous system, and in disorganised attachment both the sympathetic and the parasympathetic nervous system are impaired and dysregulated. See [26] for an overview of the subject.

Here, we highlight the results in [78], where the authors examined amygdala activation, feelings of irritation, and the use of excessive force as indicated by grip strength during exposure to infant crying and scrambled control sounds in 21 women without children. Individuals with insecure attachment representations, based on Berkeley Adult Attachment Interview [43], showed heightened amygdala activation when exposed to infant crying compared to individuals with secure attachment representations. In addition, insecure individuals experienced more irritation during infant crying and used more excessive force than individuals with a secure representation.

We can view attachment schemas as a type of implicit memory that has been sculpted in the brain by repeated experience of broadly similar interactions with a primary care giver [26, p. 139]:

> [A]ttachment schemas are a category of implicit social memory that reflects our early experience with care takers. Our best guess is that these schemas reflect the learning histories that shape experience-dependent networks connecting the orbital frontal cortex, the amygdala, and their many connections that regulate arousal, affect and emotion. It is within these neural networks that interactions with caretakers are paired with feelings of safety and warmth or anxiety and fear.

2.3 Attachment insecurity and vulnerability to mental disorder

Since the early attachment schemas are deeply embedded in the brain, their impact on the child's and later the adult's internal working model with which the social environment is processed, interpreted and responded to throughout life can hardly be overestimated. In this section, we will see that insecure attachments and the resulting incapacity to regulate strong emotions will have lasting influence on the psychological conditions of the individual. In the past few decades, there has been increasing evidence to suggest that the root cause of much mental illness lies in a sub-optimal capacity for affect regulation [85]. The adverse impact of early attachment insecurity on the capacity to regulate strong emotions and thus to fend off psychological disorders and mental illness goes very wide.

Bowlby himself emphasised the relationship between attachment problems and many psychiatric disorders [14, p. 152]:

> Advocates of attachment theory argue that many forms of psychiatric disturbance can be attributed either to deviations in the development of attachment behaviour or, more rarely, to failure of its development; and also that the theory casts light on both the origin and the treatment of these conditions.

We now highlight the main findings of Mikulinceri and Shaver in their 2012 review article in World Psychiatry [70], which provides a recent update on Attachment Theory. First and foremost, the authors report that

> attachment insecurity is a major contributor to mental disorders.

Early interactions with inconsistent, unreliable, or insensitive primary care-givers disrupt the development of a secure, self-regulated psychological foundation, which undermines building an increasing capacity to cope with stress and thus predisposes an individual to mental breakdown in crisis situations in adult life. The authors argue that attachment insecurity in childhood therefore creates an overall vulnerability to psychological and mental disorders, with the particular symptomatology depending on genetic, developmental, and environmental factors. It is, however, the combined impact of attachment insecurity with childhood trauma, neglect or abuse that is a predictor of psychological and mental disorders in later life. In their earlier work [69], these authors reviewed hundreds of cross-sectional, longitudinal, and prospective studies of both clinical and non-clinical samples and concluded:

> [A]ttachment insecurity was common among people with a wide variety of mental disorders, ranging from mild distress to severe personality disorders and even schizophrenia.

They have also reported in their review article more recent findings to show that

> [attachment insecurities are] associated with depression....., clinically significant anxiety...., obsessive-compulsive disorder....., post-traumatic stress disorder (PTSD) ....., suicidal tendencies ....., and eating disorders.....

Attachment insecurity, it is asserted, also plays a key role in various personality disorders with specific attachment insecurity correlating and corresponding to different disorders[70]:

> Anxious attachment is associated with dependent, histrionic, and borderline disorders, whereas avoidant attachment is associated with schizoid and avoidant disorders.

In addition, according to the review article, apart from the problem of emotion regulation, two other basic pathways, mediate between attachment insecurity and psychopathology, namely those involved in (i) problems of self-representation, such as

> lack of self-cohesion, doubts about one's internal coherence and continuity over time, unstable self-esteem, and over-dependence on other peoples approval,...

and (ii) interpersonal problems, so that:

> ... avoidant people generally had problems with nurturance (being cold, introverted, or competitive), and anxious people had problems with emotionality (e.g., being overly expressive). These problems seem to underlie insecure individuals self-reported loneliness and social isolation .... and their relatively low relationship satisfaction, more frequent relationship breakups, and more frequent conflicts and violence....

2.4 Impact on psychotherapy

Attachment Theory has influenced nearly all forms of psychotherapy including psychoanalysis and psycho-dynamic therapy [39], and its impact on Cognitive Behavioural Therapy, as the most widely used type of therapy today, has led to Schema

Therapy [102]. In general, clinicians have used the concepts and findings of Attachment Theory to understand, address and resolve the attachment issues that their clients bring into therapy. The therapeutic framework, according to Attachment Theory, should be perceived by the client as a safe environment in which early attachment insecurities could in principle be dealt with and replaced with a secure attachment based on the working relationship with the therapist [74, 27]. In [95], after an extensive review of Attachment Theory, a model of treatment based on this theory is proposed in which the therapist's interventions are tailored to the attachment needs of the client. The aim is to help the client to use the verbal and non-verbal relationship with the therapist to internalise a sense of secure base that was not created as a result of early child-parent interactions.

The Adult Attachment Interview (AAI) scoring system was developed by George, Kaplan and Main [43] and is designed to retrospectively classify the childhood attachment type of adults. It consists of a number of questions to assess the person's understanding of their early childhood relationships with parents. The pioneering work of Pierson et al. [75] examined the notion of earned security using the Adult Attachment Interview scoring system. Earned-security classifies adults who in the AAI describe difficult, early relationships with parents, but who have been able to reflect into their experience through psychotherapy or a constructive marriage and as a result have developed secure working models in their adulthood as shown by their high coherency scores. Mikulincer and Shaver [70] also provide evidence that a sense of security provided by a psychotherapist improves a client's mental health and can lead to earned secure attachment. According to the study of a group of adults by Pearsona1, Cohna, Cowana and Cowan in [75], however, earned securers have comparable depressive symptomatology as insecurers.

Another main focus of the review article [70] is what they call the healing effects of attachment security, which is directly related to Self-attachment protocols. Whereas attachment insecurities create vulnerability to mental illness, the review argues that

> the creation, maintenance, or restoration of a sense of attachment security should increase resilience and improve mental health.

The authors then report on studies of experiments published in 2001 and 2007 on so-called "security priming", which artificially activate mental representations of supportive attachment figures, for example, by

> subliminal pictures suggesting attachment-figure availability, subliminal names of people designated by participants as security-enhancing attachment figures, guided imagery highlighting the availability and supportiveness of an attachment figure, and visualization of the faces of security-enhancing attachment figures.

The authors indicate that security priming improves participants' moods even in threatening contexts and eliminates the detrimental effects of threats on positive moods, and found that subliminal priming with security-related words mitigated cognitive symptoms of PTSD (heightened accessibility of trauma-related words in a Stroop-colour naming task) in a non-clinical sample.

3 Attachment objects

When secure attachments are not available in normal relationships, attachment figures or attachment objects have been used by human beings to regulate their emotions and create a sense of felt security for themselves. Such attachment substitutes are often used by securely attached individuals to cope with extreme forms of distress such as loss of a loved one, war atrocities, human inflicted traumas, and horrific accidents [47]. While these attachment substitutes are often external objects, the meaning individuals attribute to such an object and the relationship, interactions and contract agreements they establish with it are highly personal, subjective and are created often meticulously by the individuals themselves who may nevertheless use and copy ideas from others. These attachment objects are employed by individuals with the aim of attaining the kind of inner-felt security that can be observed in securely attached children or adults in dyadic relationships. In fact, experiments with monkeys show that higher primates are able to use such attachment objects, which we will describe next.

3.1 Evidence in Ethology

By late 1950's, Bowlby had for several years studied separation anxiety in children who were separated from their mothers but he could not explain his clinical findings using his psychoanalytic training. A number of experiments with monkeys by the leading ethologist Harry Harlow however attracted Bowlby's attention and had a profound impact on his ideas. Bowlby wrote at the time [13]:

> The longer I contemplated the diverse clinical evidence the more dissatisfied I became with the views current in psychoanalytical and psychological literature and the more I found myself turning to the ethologists for help. The extent to which I have drawn on concepts of ethology will be apparent.

Motivated by Bowlby's work on separation anxiety, Harlow experimented on infant rhesus monkeys with surrogate dummy mothers that were either bare-wired or cloth-covered. He found that the infant monkeys had an overwhelming preference for cloth-covered mothers and would spend their time clinging to the cloth mother [48]. These experimental studies provided further support for attachment theory [28].

A series of later experiments by Harlow in the 1960's [91, p. 487], regarded as unethical today, showed that clinging to the cloth-covered surrogate mother served as a way of regulating anxiety. Two groups of infant rhesus monkeys were removed by Harlow from their mothers, and given a choice between either a cloth-covered or a bare-wired surrogate mother. In the first group, the cloth-covered mother provided no food, while the wire mother did. In the second group, the cloth-covered mother provided food while the bare-wired mother did not. As expected the infant monkeys would cling to the cloth-covered mother whether it provided food or not and the

infant monkeys went to the wire surrogate only when it provided food. Whenever frightened, the infant monkeys would run to the cloth mother for protection and comfort, notwithstanding which mother provided them with food. Placed in an unfamiliar room with their cloth-covered surrogates, the monkeys would cling to them until they felt secure enough to explore and then would occasionally return to the cloth mother for comfort. Monkeys who were placed in an unfamiliar room without their cloth mothers, however, would freeze in fear and cry, crouch down, or suck their thumbs. Some of the monkeys would even run from object to object, apparently searching for the cloth mother as they cried and screamed. Monkeys placed in this situation with their wire mothers exhibited the same behavior as the monkeys with no mother.

The cloth-covered surrogate mother thus provided for the infant monkeys an attachment object for affect regulation. Bowlby in fact described this kind of attachment object both for the infant monkeys and the human child as we will see next.

3.2 Children's attachment objects

While the word attachment has a broad meaning in every day life, Attachment Theory as conceived by John Bowlby has a narrow domain of discourse which is focused on the relationship between two individuals of the same species, in particular the child-parent and the adult-adult relationships. However, according to Bowlby, when normal attachment relations are unavailable an inanimate object can play an important role as an "attachment figure". In his first seminal work on Attachment Theory, after providing an example of such an inanimate attachment object for an infant chimpanzee, who had been cared for by a human foster-mother, he writes [15, p. 313]:

> Many other examples of such behaviour in primate infants brought up in atypical surroundings could be given.
>
> Thus it seems clear that, whether in human infants or monkey infants, whenever the "natural" object of attachment behaviour is unavailable, the behaviour can become directed towards some substitute object. Even though it is inanimate, such an object frequently appears capable of filling the role of an important, though subsidiary, attachment-"figure". Like a principal attachment-figure, the inanimate substitute is sought especially when a child is tired, ill or distressed.

Bowlby's "attachment figure" or "substitute object" described above had been previously studied by Donald Winnicott [97], the renown British paediatrician and child-psychoanalyst, who had coined the term "transitional objects" for it. The concept of transitional object was introduced by him in 1953 to describe "comfort objects" such as pillows, blankets and soft toys that a child becomes intensely and passionately attached to. According to Winnicott, for toddlers with good enough mothers, these attachments to transitional objects play a key role in ego development: the child projects the comforting properties of a good enough mother to the

inanimate object which, unlike the mother who can temporarily disappear, is always under the control of the child whether the mother is present or not. By practicing and interacting with the transitional object, a mother substitute, the child then acquires the capacity for self-soothing by internalising the good enough mother and is able to withstand increasingly longer absences of the mother. Later researchers have formulated a number of key functions of transitional objects, including separation-individuation, libidinal object constancy, capacity for object relation and empathy and symbolisation and creativity [65].

In 1958, Winnicott also introduced another concept, namely the "capacity to be alone" [99]. His article starts by asserting that

> I wish to make an examination of the capacity of the individual to be alone, acting on the assumption that this capacity is one of the most important signs of maturity in emotional development.

He theorised that this capacity can be developed in children who have good enough mothers and have thus, in psychoanalytical terminology, introjected or internalised a good object in their inner psychic world. In Winnicott's view this capacity can however only take shape by the experience of

> being alone, as an infant and a small child, in the presence of the mother.

According to Winnicott, only by acquiring the capacity to be alone the child can discover its "true self" in contrast to "a false life based on reactions to external stimuli. It is based on this self-discovery that the child's capacity to be alone has been proposed as the foundation of independence and creativity later in life, and is regarded as "an aspect of emotional maturity" [89, p. 18].

The notion of a "self-object" in Heinz Kohut's self-psychology, an established school of object-relation psychoanalysis, also has many parallels with an attachment object. Self-objects are, according to Kohut, external persons (including parents and therapists), objects or activities that [59, p. 220]

> support the cohesion, vigor, and harmony of the adult self... ranging from cultural self-objects (the writers, artists, and political leaders of the group - the nation, for example - to which a person feels he belongs.....) to the mutual self-object functions that the partners in a good marriage provide for each other.

According to Kohut, it is through empathic responsiveness that self-objects support the individual's developmental needs of mirroring, which leads to regulation of a cohesive sense of self and is the most vital part of cure [59, p. 65-66]:

> [H]ow does self psychology perceive the process of cure? The answer is: as a three-step movement, the first two steps of which may be described as defense analysis and unfolding of the transferences, while the third step–the essential one because it defines the aim and the result of the cure–is the opening of a path of empathy between self and self-objects, specifically, the establishment of empathic in-tunes between self and self-object on mature adult levels.

3.3 Religion as attachment object

John Bowlby believed that attachment continues in one way or another later in adulthood [12, p. 588]:

> Probably in all normal people [attachment] continues in one form or another throughout life and, although in many ways transformed, underlies many of our attachments to country, sovereign, or church.

Attachment theorists have in later years objected to the use of the term "attachment", as meant in the context of attachment theory, for any type of bond that human beings create [66, p. 846]. In particular the use of the term "attachment" for patriotism, as in the above quotation, has been received with scepticism [54, p. 803]. However, there is now a consensus among attachment theorists for the notion of "religion as an attachment object", which we will elaborate in this section.

In his book "Theological Imagination: Constructing the Concept of God", Gordon Kaufman adopts the tenets of Attachment Theory and quotes John Bowlby to argue that human beings are at their happiest when they feel secure in some trusted relationships and then provides this quotation by him [52, p. 59]:

> Since in the lives of all of us our most trusted companions are our attachment figures, it follows that the degree to which each of us is susceptible to fear turns in great part on whether our attachment figures are present or absent.

Later Kaufman goes on to argue that in the Christian tradition God is above all a loving and caring father and therefore concludes [52, p. 67]:

> The idea of God is the idea of an absolutely adequate attachment-figure.

While Freud had regarded the notion of God as projection of father and considered it as a delusion [41], attachment theorists began to study the different aspects of the relationship individuals perceive to have with God in the context of attachment. The idea that God, or any deity or religion, can be considered as an attachment object has been investigated since 1990s by a group of social psychologists and there is now a considerable amount of studies which provide evidence for this hypothesis in both Christian and Jewish religions; see the comprehensive review [47] by Granvist, Mikuliner and Shaver [47], which we will summarise below.

The review [47] provides a systematic summary of the work of the authors and that of other researchers on the notion of "Religion as Attachment". First, there is the phenotypic resemblance between parental attachment and believers' relationships with God. Asked which of the following best describes their view of faith–(i) a set of beliefs; (ii) membership in a church or synagogue; (iii) finding meaning in life; or (iv) a relationship with God– most Americans by far chose the last description. Central in the perceived relationship of the believer with God is the experience of "love", which is closely akin to the relationship of a child with an adult attachment figure. In addition, the images of God in religious texts and in believers' description of God's traits are also similar to attributes of parenting, and the main underlying factors are "availability" and "benevolence". Second, there are similarities between

the criteria of attachment relationships such as proximity seeking and the believers' perceived relationship with God such as his perceived omnipresence, which is felt by the believer when they visit a place of worship and particularly when they pray.

Third, one of the main functions of secure attachment, i.e., to provide a safe haven when there is danger or distress has its direct parallel in the notion of God as a safe haven. In times of extreme stress and trauma, believers resort to praying to God to alleviate their fear and anxiety. Several studies have confirmed that after loss of a loved one, religious practice and prayer increases among believers and these correlate with successful coping at these critical times [55]. Interestingly, in regard to separation anxiety, one study suggests that even subliminal perception of threat can activate the attachment system of a believer to increased access to the concept of God and supports correspondence between internal working models of parents and God [10].

Fourth, the other main function of secure attachment, i.e., to furnish a secure base for exploring the world and taking up challenges in life, has its parallel in the notion of "God as a wiser and stronger secure base", which is in line with Bowlby's assertion that children consider their parents as stronger and wiser than themselves [15]. In an extensive work on empirical research on religious practice [8, p. 158–164], it is shown that having an intrinsic orientation in religious practice, i.e., considering it as " an end in itself–a final, not instrumental, good", is correlated with two forms of mental health, namely "freedom from worry and guilt" and "a sense of competence and control". Studies on the psychological effect of religious conversion shows that there is generally a significant decrease in negative affects and a notable increase in well-being in individuals who go through religious conversion; see [8, p. 101-106] and [92]. The review [47] also summarises several studies to confirm that particular aspects of religious beliefs that correlate more strongly with psychological well-being, i.e., "divine relationships" and "praying", are precisely those that are in line with the model of religion as an attachment object. In addition, Kirkpatrick, Shillito and Kellas in [57] concluded in their study on the effect of religious practice and loneliness that having a personal relationship with God predicted reduced loneliness despite controlling other factors of interpersonal support.

Furthermore, the review describes two hypotheses that describe two different pathways to God as an attachment object for individuals, which are related to the individual differences in the output of the attachment system. The first is the "compensatory pathway" to reduce distress generally chosen by individuals who have had insensitive primary care-givers resulting in attachment insecurities. In particular, sudden religious conversions are correlated with insensitive parenting [56] and a number of studies have indicated that increase in religiousness among individuals with insensitive parenting is precipitated with severe emotional upheavals [46]. This is consistent with the findings of William James in his classic book "Varieties of Religious Experience" who called these individuals "second born" after having a sick soul with a great amount of anguish and pain [50]. The second hypothesis is the "correspondence pathway", generally chosen by individuals who have had caring and religious parents. This pathway expresses a continuity in secure attachment with religious parents in children who grow up to hold the religious orientation

of their parents. In his book, William James called these people "once born", i.e., individuals who have a rectilinear life with a happy mind.

Finally, the authors point out the limitations of the concept of religion-as-attachment model and suggest a more inclusive framework for spiritual attachment objects that includes notions such as mindfulness from non-theistic religions like Buddhism and New Age spirituality.

In more recent years, a similar study on Islamic scripture and spirituality has been undertaken to examine Allah as an attachment figure in the Islamic faith. In [11], the authors investigate whether Muslims seek proximity with a loving God as a safe haven in times of distress and a secure base for living in a challenging world. They consider five different types of Islamic texts, namely, (i) the divine names or attributes of Allah, (ii) stories in the Qur'an that represent attachment relations between Allah, His prophets and people, (iii) verses of the Qur'an with an emphasis on the caring and supportive relationship between Allah and His people, (iv) divine sayings and prophetic inspirations that project Allah as a caring and supportive attachment figure, and (v) supplications which describe the believers' relationship with Allah. On all these themes, the relationship of a Muslim believer with Allah is consistent with the relationship with an attachment figure and the paper comes to similar conclusions as in the Christian and Jewish faiths.

Closely related to the concept of God as an attachment object is the notion of God as a transitional object in a sense used by Winnicott. According to him, a transitional object for the child has an illusory aspect and he postulates a general transitional space which has some illusory aspect [98, p. 3]:

> I am staking a claim for an intermediate state between a baby's inability and his growing ability to recognise and accept reality. I am therefore studying the substance of *illusion* that which is allowed to the infant, and which in adult life is inherent in art and religion....

William Meissner, a Jesuit and a psychoanalyst, has used the notion of a transitional object to explain the psychology of religion and, in particular, the psychology of praying. After elaborating on Winnicott's view of transitional objects with their illusory aspect, he writes [68, p. 177] :

> Illusion, therefore, becomes in Winnicott's view a developmental form of transition to reality, in the sense that without the capacity to utilize transitional objects and to generate transitional forms of experience the child's attempt to gain a foothold in reality will inevitably be frustrated. Illusion in this view is not an obstruction to experiencing reality but a vehicle for gaining access to it.

In fact, Winnicott had claimed that the area of illusory experience is a vital potential space for psychological development [98, p. 110]:

> It is useful, then, to think of a third area of human living, one neither inside the individual nor outside in the world of shared reality. This intermediate living can be thought of as occupying a potential space, negating the idea of space and separation between the baby and the mother, and all developments derived from this phenomenon. This potential space varies greatly from individual to individual, and its foundation is the baby's trust in the mother *experienced* over a long-enough period at the critical stage of the separation of the not-me from me, when the establishment of an autonomous self is at the initial stage.

Meissner then asserts [68, p. 183]:

> Within this potential space, then, man must revive the roots of his capacity for creative living and for faith experience.

In this relation, Erik Erikson, a renown developmental psychologist and psychoanalyst, writes the following on religious experience with an implicit reference to Freud's view of religion as regression to childhood [18, p. 176]:

> But must we call it regression if man thus seeks again the earliest encounters of his trustful past in his efforts to reach a hoped-for and eternal future? Or do religions partake of man's ability, even as he regresses, to recover creatively? At their creative best, religions retrace our earliest inner experiences, giving tangible form to vague evils and reaching back to the earliest individual sources of trust; at the same time they keep alive the common symbols of integrity distilled by the generations. If this is partial regression, it is a regression which, in retracing firmly established pathways, returns to the present amplified and clarified.

Later in his book, Meissner writes the following about the individual believer's praying [68, p. 182]:

> It is here that the qualities of the God-representation and their relationship to the believer's representation become immediate. The God he prays to is not ultimately the God of the theologians or of the philosophers, nor is this God likely to be in any sense directly reconcilable with the God of Scripture. Rather, the individual believer prays to a God who is represented by the highly personalised transitional object representation in his inner, private personally idiosyncratic belief system.

He then goes on to write:

> One might say that in prayer the individual figuratively enters the transitional space where he meets his God-representation. Prayer thus becomes a channel for expressing what is most unique, profound, and personal in individual psychology.

We note that in the three cases of attachment objects considered in this section, i.e., surrogate cloth-covered monkeys used by infant monkeys in Harlow's experiments , comfort objects used universally by human children and deities used widely in religious practice by adults, the attachment object actually is or is perceived to be an *external* object. We will see how an internal object is used in Self-attachment later in the article. Next, however, we see how the neural activation in the brain corresponding to a relationship with an external attachment object like God overlaps with that of adult love and maternal love.

4 fMRI Studies on Bond Making

Since 2000, there have been three different types of fMRI studies on bond-making with respect to adult love, maternal love and religious praying which show that these three different forms of bonding in human beings share a common denominator in terms of activation of the neural pathways in the reward system of the human brain.

Bartles and Zeki in [6] reported on fMRI studies of passionate/romantic adult love. In their experiment, six men and and eleven women, who were passionately in love with their partners, stared at photos of their partners or at photos of their friends for about 17 seconds. The conclusion was that looking staringly at the photo of a beloved partner increased activation of the dopaminergic- related brain areas such as the caudate nucleus and putamen. These findings were reinforced by fMRI experiments reported in [5] by Aron et al. on partners in the early stage of passionate love, which showed increased activity in dopamine- rich subcortical brain areas, the ventral tegmental area and caudate nucleus.

In [7], Bartles and Zeki conducted an fMRI experiment, similar to that in [6], on twenty mothers when each stared at the photos of their own child, compared to another child of the same age with whom they were acquainted with, their best friend, and photographs of another person they were acquainted with. There was increased activity in the dopaminergic-rich sub- cortical brain areas (caudate nucleus, putamen, subthalamic nucleus, periaqueductal gray, substantia nigra, and lateral thalamus). There were specific differences in activation patterns in romantic love and maternal love, in particular the activation of the periaqueductal (central) gray matter (PAG) was observed in maternal but not passionate love. However, the conclusion was that there are neural correlates common to both maternal and romantic love, which are based on increased activation of the dopaminergic rich subcortical regions of caudate nucleus and putamen.

The above fMRI studies were related to bond making between human beings. In a completely new type of experiment, Uffe Schjoedt et al. in [83] investigated how performing religious prayers changed the neural activity in a group of Danish Christians. The devout believer had five tasks to perform that included two prayers, the Lords Prayer, as a highly formalized prayer, and a personal prayer as an improvised prayer. The participants all reported that they were strong believers in God's existence and regularly prayed. The result was the activation of the caudate nucleus in the participants when praying, which supports the hypothesis that religious prayer is capable of stimulating the dopaminergic system of the dorsal striatum in practicing individuals. This conclusion is consistent with research on the human striatum indicating that repeated behaviours which are expected to elicit future rewards evoke activity in the dorsal striatum. Furthermore, regarding a related study, the authors say:

> we found no significant caudate activation of self-reported religious persons, who did not pray regularly. While one can argue that prayer involves interaction with an abstract idea of some deity in one form or the other, as far as the brain activity is concerned, it is no different than normal interpersonal interaction.

On this subject, Uffe Schjoedt, the lead author of the article, writes [82]:

> Importantly and somewhat contrary to the widespread assumption that communicating with God constitutes a unique experience reserved for believers, our findings suggest that praying to God is comparable to normal interpersonal interaction, at least in terms of brain function. Praying, it seems, is subserved by the basic processing of our biologically evolved dispositions like other complex cultural phenomena, in this case the evolved human capacity for social cognition.

These findings give further support to the concept of God as an attachment object for believers as described in the previous section. The devotional personal relationships believers have with their God have neural correlates with the passionate relationships in adult love and maternal love. Being in love, whether with your child, your partner or a deity, has a common denominator in that in all these cases the reward system of the brain is activated in the anticipation of some reward which gives incentive, energy and hope to the individual to maintain and strengthen their relationship with the beloved object by carrying out an appropriate set of tasks.

5 Self-attachment

As we have seen in Section 2.3, insecure attachment in childhood in general, and disorganised insecure attachment in particular, makes us vulnerable as adults to psychological disorders and mental illness. From this, it follows that a holistic approach to Computational Psychiatry would seek to examine how individuals might be enabled to earn secure attachment in adult life. We have seen in previous sections how psychotherapy, constructive marriages and the compensatory pathway in religious practice can help individuals earning secure attachment. It was also shown how attachment objects are used in very different contexts by infant monkeys, human children and believers to create a bond with an inanimate or abstract object and use it for emotion self-regulation.

The question now arises as to whether it is possible to develop a self-administrable protocol, based on developmental psychology and neuroscience (as described in Sections 2) that can help individuals use neuroplasticity and long term potentiation to create their own attachment objects in order to earn secure attachment.

It is proposed in [31] that this is a feasible task. The dyadic child-parent interactions of a good enough parent and a child can be self-administered by an individual who is considered to consist of an inner child and an adult self. The inner child, representing the emotional self, rooted mostly in the right brain and the limbic system, becomes dominant under stress, whereas the adult self corresponding to the logical self, rooted mostly in the left brain and the prefrontal cortex, is dominant in the absence of stress. The adult self connects to and imaginatively creates an affectional bond with the inner child taking up the role of a new primary carer who retrains the inner child to acquire the capacity for emotion self-regulation. In the process of these interactions, the aim is for the inner child to be raised to emotional maturity while the adult self is transformed to a secure attachment object for the inner child.

The creation of the internal affectional bond with the inner child is proposed to activate the dopaminergic pathways of the reward system in the brain. This activation, we argue, provides the energy, incentive and hope to persevere with the protocol and plays the same role that the primary care-giver's love for the child has in the healthy emotional growth of the child. This bond-making is the distinguishing feature of Self-attachment and is in line with fMRI studies on romantic and maternal

love as well as religious practice described in Section 3.3. It is also consistent with Bowlby's description of how bonds are created and maintained [14, p. 155]:

> Thus, many of the most intense emotions arise during the formation, the maintenance, the disruption, and the renewal of attachment relationships. The formation of a bond is described as falling in love, maintaining a bond as loving someone, and losing a partner as grieving over someone. Similarly, the threat of loss arouses anxiety and actual loss gives rise to sorrow; whilst each of these situations is likely to arouse anger. The unchallenged maintenance of a bond is experienced as a source of joy.

Self-attachment aims to create an unchallenged maintenance of the bond between the adult self and the inner child so that it becomes a source of joy for the individual. Subsequent to the formation of the Self-attachment bond, the training practices that are at the basis of the adult self and inner child interactions emulate those of "good enough" primary care givers, as described in Subsection 2.1, to minimise negative and maximise positive affects and modulate the inner child's arousal level. It is hypothesised that based on neuroplasticity and long term potentiation, these practices lead to neural circuits corresponding to secure attachment that will increasingly challenge the sub-optimal circuits produced as a result of insecure attachment in childhood as described in Subsection 2.2. While the sub-optimal circuits cannot be wiped off and under high stress can become dominant again for a while, the new optical circuits will gradually counter them effectively and reduce the severity and the duration of the resulting symptoms.

It is on this basis that the notion of Self-attachment has been proposed in [31], which, in a broad sense of the term, can be regarded as a type of self-directed behaviour and interaction that employs a real or imaginative object of devotion and affection and is practiced regularly in order to regulate emotions and harmonise social interactions. We submit that the use of attachment objects as described in Section 3, whether by infant monkeys, human children or by adults in religious practice, has many parallels with the notion of Self-attachment. In these cases, the attachment object is external or is perceived to be external and the emotion regulation by the individual is therefore mediated by an externally perceived object.

Self-attachment is essentially a self-help technique which, depending on the individual, may initially need the support of a psychotherapist for a few sessions. It aims to use neuroplasticity and long term potentiation to help individuals to create their own secure attachment objects by the direct intervention of their "adult self', representing their rational self, in order to reparent the "inner child", representing the emotional self. The attachment object to be created can be regarded as a comfort object (cf. Bowlby), transitional object (cf. Winnicott) or empathetic self-object (cf. Kohut). Self-attachment intervention seeks to closely emulate the dyadic interactions of a "good enough" primary care giver and a child by first taking a compassionate attitude to the inner child and then developing an internal affectional bond with the "inner child". This internal bonding, it is hypothesised, activates the dopaminergic reward system of the brain inducing hormones and neurotransmitters including dopamine, serotonin, oxytocin and vasopressin that provide the incentive, energy, hope, tranquillity and caring attitude required for persevering with the

reparenting protocol to achieve emotion self-regulation as in secure attachment of children [84, p. 14].

Self-attachment can be regarded as an extension of attachment theory but it is also related to and incorporates ideas from a range of psychotherapeutic methods. This includes the notion of "inner child" from transactional analysis [88], Mentalisation [4]– defined as the capacity to understand the emotions and mental states of the other people as well as those of oneself– exposure as in behavioural therapy [1], compassionate focused psychotherapy [44], schema therapy and reparenting [102] and object-relation psychodynamic therapy in a wider sense of the term in which objects can be impersonal as well as personal [89, p. 150-152]. Self attachment integrates these techniques into its main focus of intervention, which is the creation of an internal affectional bond to emulate what occurs naturally between an infant and a parent. Self-attachment also employs protocols such as singing, dancing and massage that are known to increase dopamine, serotonin, oxytocin and reduce cortisol levels [58, 51, 72, 37]. It can also be combined with any well-established therapeutic technique.

5.1 Playing and Role Playing

The internal interactions in Self-attachment resemble role playing, in which the individual plays simultaneously both the role of the child within and that of the adult self. This shows that, while these interactions aim to create new types of cognition and behaviour corresponding to secure attachment, Self-attachment is in a sense a form of playing. It is therefore useful here to highlight the significance of play in general in psychotherapy.

As explained in the previous section, Winnicott considers a potential illusory sphere of play between the inner reality of an individual and the external reality. He also presents the hypothesis that psychotherapy can only be successful when both the therapist and the patient play [98, p. 54]:

> The general principle seems to me to be valid that *psychotherapy is done in the overlap of the two play areas, that of the patient and that of the therapist.* If the therapist cannot play, then he is not suitable for the work. If the patient cannot play, then something needs to be done to enable the patient to become able to play, after which psychotherapy can begin. The reason why playing is essential is that it is in playing that the patient is being creative.

As far as child development is concerned, play has been recognised as vital for the cognitive, physical, social, and emotional well-being of children and for maintaining strong parent-child bonds [45]. There has been a growing body of evidence in children supporting the many connections between cognitive and social competence as well as abstract thinking on the one hand and high-quality pretend play on the other hand. In particular, role playing in children has been linked to cognitive functioning and impulse control. Pretense starts in children age between one and two and plays a vital role in young children's lives through the primary school years [9].

In addition, role playing is an established method in psychotherapy and is defined by Corsini [25, p. 6] as follows:

> Essentially, role playing is a "make believe" process. In therapy, the patient (and if it is to be an interactional situation, the others involved) will act for a limited time "as if the acted-out situation were real".

Asserting that role playing can even be used in self-therapy, Corsini then postulates that role playing has the following basic features [25, p. 5 and 9]:

- Is a close representation of real life behaviour.
- Involves the individual holistically.
- Presents observers with a picture of how the patient operates in real life situations.
- Because it is dramatic, focuses attention on the problem.
- Permits the individual to see himself while in action in a neutral situation.

The dyadic interactions in Self-attachment between the adult self and the inner child differ in two ways from the usual role playing as in the first item listed above: (i) the behaviour of the inner child is not just a close representation of real life behaviour but rather *the real life behaviour itself*, and (ii) the behaviour of the adult self, who follows the Self-attachment protocol, is the *optimal behaviour of a "good enough" parent in relation to a child*. In the next section, we turn to a more detailed outline of the various stages of Self-attachment.

5.2 Self-Attachment protocol

There are four stages in the Self-attachment protocol which are briefly described here [31]:

(1) Introduction to secure Self-attachment therapy. The Self-attachment protocol is challenging and demanding for any volunteer as it requires a great deal of dedication and motivation. For this reason, it is essential to understand why so much time and effort should be invested in this method before it can have an impact. Therefore, in the preliminary stage, the individuals become familiar with the scientific basis and the underlying hypothesis of the proposed Self-attachment therapy. This includes a basic introduction to attachment theory, regulation theory and their neural correlates, fMRI studies on being in love in the case of maternal and romantic love as well as that of bonding with abstract and imaginative objects as in prayer, neuroplasticity and long term potentiation.

(2) Connecting with the "inner child". In this first stage of the protocol, the volunteers start to have a relationship with their inner child with a view to establish empathy and ultimately compassion with the child. While looking at photos of their childhood, they think introspectively and recall their basic childhood environment including their relationships with parents and other care-givers. The aim is to have a feeling for the inner child as a result of these exercises. Since the early attachment type of a child is formed in the pre-verbal years, when visualisation is the main tool

for observation and sensing, there is much focus on imagery in this stage. A happy or positive looking photo of childhood that has always been favoured is selected by the volunteer as well as a sad or gloomy looking photo that has been avoided, disliked or less fond of. Several novel exercises are designed to connect to the inner child in various emotional states while the eyes are kept closed: trying to visualise the two chosen childhood photos, to imagine that the child that they were is present and is close to them and that they can touch and hold this child. The objective of the this stage is to conceptualise the inner child as concretely as possible and develop empathy and then compassion toward it.

(3) Making an affectional bond with the inner child. In this stage an imaginative but passionate affectional bond is made with the inner child that is subjectively experienced as falling in love. This resembles passionate devotion to a deity that has neural correlates with maternal and romantic love. It is hypothesised that this step can in principle be taken by all individuals based on their primary narcissism, a notion of "self-love" in children originally introduced by Freud as a defense mechanism that is to protect the child from psychic damage during the formation of the individual self [41]. Bowlby has himself argued that separation anxiety in children from their mothers, which is the root cause of insecure attachment, is a form of injury to primary narcissism [15, p. 11].

The inner child is subsequently adopted imaginative by the volunteers who vow to consistently support and love the inner child to reprocess past traumatic episodes and reparent the child to emotion self-regulation. The imaginative bond making is in practice attained by passionately and repeatedly reciting a favourite happy love song while staring at the positive looking childhood photo trying to rekindle happy memories. The aim here is to bring the inner child into life, excitement and joy again, inducing dopamine release and providing energy and hope for the volunteer who requires constant motivation to keep up the momentum and resolve to persevere with carrying out the protocol. This is in line with latest findings in neuroscience on singing. The study in [51] found increased activation in nucleus accumbens for singing as opposed to speaking words of a familiar song and [58] reported increased activation in regions including caudate nucleus and putamen when professional classical singers imagined singing an aria (love song). In addition, [81] revealed dopamine release in caudate nucleus and nucleus accumbens during anticipation and experience of peak emotional response to passive listening to self-reported pleasurable music.

(4) Developmental retraining and re-parenting the inner child. The last and main stage consists of several types of interactions between the adult self and the inner child that emulate the function of a good enough parent in interacting with a securely attached child in order to minimise the negative emotions, named the Sad-Child protocol, and to maximise the positive affects, named the Happy-Child protocol. We provide one example here on how to reprocess painful and traumatic past events: the volunteers with their eyes closed recall some traumatic episode in their childhood, remembering in as much detail as possible the associated emotions of fear, helplessness, humiliation and rage. Then, they imagine that their inner adult responds quickly to the child in distress by embracing, cuddling, and loudly reassur-

ing the child. Cuddling the inner child is simulated by giving oneself a head, face or neck massage, which is known to reduce cortisol levels and increase oxytocin and endorphin release; see [26, p. 103] and [37]. By revisiting the neural circuits of past traumas, these sessions thus induce dopamine, serotonin, oxytocin and vasopressin secretion and are designed to build new optimal neural circuits in relation to the old pathological ones.

A basic undertaking by the volunteers throughout the treatment period is to gradually construct, using their own imagination, a visually potent picture of the protocol that depicts a secure attachment object, for example as a new bright and solid house erected and built in the place of a dark and derelict shelter, which depicts insecure attachment. This visual construction, which either remains completely in the mind or is drawn on paper, symbolises the secure attachment the volunteers would earn themselves in contrast to their past insecure attachment anxieties.

5.3 Distinguishing characteristic and proof of concept

The distinguishing characteristic of Self-attachment therapy is the internal affectional bond that is self-administered to emulate the loving relationship of a primary caregiver and a child. The imaginative but passionate relationship between the adult self and the inner child mimics the real interactions of a parent-child dyad that lead to secure attachment in the first years of the child's development. These interactions aim to maximise the positive affects and strengthen the bond and homeostasis between the adult self and inner child, similar to the real interactions of loving parents and their children as described in Section 2.1. They have the combined result of creating more positive affects and establishing an intimate, internal dialogue of adult self with the inner child. This combination is unique to Self-attachment and, in particular, provides a more effective tool to tackle and contain negative affects and the corresponding psychological disorders.

There have been a number of case studies of Self-attachment undertaken by volunteers since 2010 and by clients of professional psychotherapists trained in the protocol since 2014, which were first reported in [31] as mentioned in the Introduction. A detailed report of a number of case studies is now under preparation.

As pointed out in the Introduction, the central idea in the virtual reality experiments reported in [35, 36] is similar to the basic intervention in the first stage of Self-attachment described in (2) above. The difference is that in Self-attachment the child is displayed, imagined and perceived as the "inner child" of the individual, representing the emotionally unregulated childhood of the individual with its own history of attachment insecurities. While this is a crucial distinction that can lead to a much more effective intervention, the results reported in these two papers provide a proof of concept of Self-attachment.

It may be argued here that Self-attachment, as described in Subsection 5.2, is not a natural undertaking. There are three basic points to be made to counter this argument.

First, looking after yourself or taking care of yourself is a main principle of mental health in all cultures and there are many organisations and manuals dedicated to this principle for the general public. Self-attachment takes this principle further for those who have had traumatic childhood background and are thus vulnerable to mental disorders.

Second, one can argue with the same reasoning that the use of religions or deities as attachment objects for individuals is not natural. Yet, such use of religions and deities have existed for thousands of years and continue to play a significant role in the mental health of human beings.

Third, there seems to be in fact a natural role for Self-attachment in higher primates: There is some evidence for a direct but rudimentary form of Self-attachment in ethology. Experiments, on rhesus monkeys, isolated at birth, show that after six months in isolation they exhibit a type of self-directed behaviour, such as self-orality, clasping a limb or rocking, which are considered soothing and comforting since they are precisely described in ethology as the kind of actions that would have been carried out on the monkey infant by the monkey's mother if she had been present [17]. These self-directed soothing behaviours must have biological underpinnings as they are not learnt and therefore give more evidence that Self-attachment is a particular component of the attachment system discovered by Bowlby.

6 A game-theoretic model

We have argued that Self-attachment has many parallels with role playing in psychotherapy and that it can be regarded as a type of interactive play between the adult self and the inner child. In this section, a game-theoretic model for the Self-attachment protocol is presented. We first briefly review the notion of a game [42]. A strategic game is a model of decision making by a number of agents called players in which each player has a set of possible actions and in each round of the game, the players simultaneously choose their individual actions independently. A strategy profile is a particular choice of action by each player and a game is fully defined by providing the utility of each player for each strategy profile. The concept of stability in strategic games is captured by the notion of a Nash equilibrium. A strategy profile is said to be a Nash equilibrium for a given game if no player can increase its utility by deviating from its action in the strategy profile when all other players keep their actions intact. A repeated game (or iterated game) is an extensive form game which consists in some number of repetitions of some base game (called a stage game), for example a 2-person game. It captures the idea that a player will have to take into account the impact of its current action on the future actions of other players. Game theory has been applied to various areas in applied mathematics when different decisions are made by competing players; see [42].

In [16], the dynamics of interaction of a child-parent dyad for different attachment types has been modelled using two player and two action games. The two actions of the child are "Go", meaning "go to seek support from the parent" or

"Don't Go", whereas the actions of the parent are given by "Attend", meaning respond appropriately to the child's distress, or "Ignore", meaning "ignore the child's distress signal". For example, the game on the left in Fig. 1, which has a Nash equilibrium for the strategy profile (Go, Attend), is proposed for the dynamics of secure attachment, whereas the game on the right in Fig. 1, which has a Nash equilibrium for the strategy profile (Don't Go, Ignore) gives a model of avoidant attachment.

In [20], a framework is introduced which, given a game with an undesirable Nash equilibrium, will generate using reinforcement learning a dynamics which changes the utility matrix by providing additional reward for more desirable actions until a new Nash equilibrium at some predetermined desirable strategy profile is established. The change in the utility matrix is brought about by reinforcement learning and additional reward provided to one or both players for taking more desirable actions. Reinforcement learning algorithms model dopamine release (corresponding to a reward-prediction error) [101], which gives the incentive to a player to deviate from its action in the Nash equilibrium in the anticipation of future reward.

Specifically, the framework in [20], employs Q-learning, a particular type of reinforcement learning [90], which is suitable to model dopamine release [79]. As an example, a process of psychotherapeutic intervention to induce change in the behaviour of a parent with an avoidantly attached child has been modelled using attachment games, which offers internal rewards to the parent whenever the action "Attend" is selected and eventually leads to a secure attachment game.

		Parent	
		Attend	Ignore
Child	Go	**4,4**	3,3
	Don't Go	2,1	2,2

		Parent	
		Attend	Ignore
Child	Go	4,2	2,3
	Don't Go	3,1	**3,4**

Fig. 1 Left: A game with a secure NE. Right: A game with an insecure NE

The above framework can be adapted to provide a model of Self-attachment. We assume the individual undertaking the Self-attachment protocol has had an avoidant attachment in childhood and has thus internalised an adult self in the mirror image of his or her primary care-giver. Therefore, we assume that initially the inner child of the individual is avoidantly attached with the individual's adult self and their interactions can be modelled at the start by an avoidant attachment game as on the right in Fig. 1.

The two actions of the Inner Child, namely "Go" and "Don't Go" signify whether the individual seeks help from himself/herself or not, whereas the two actions of the Adult Self, namely "Attend" and "Ignore", represent the two cases when the individual takes action to comfort himself/herself or not. The four strategy profiles then describe the four possible alternatives when the Inner Child is distressed, e.g., when the individual is suffering from some anxiety or depressive symptom. The effect of Self-attachment practice is modelled by the reinforcement learning framework in [21] applied to the avoidant game so as to change it dynamically to the secure attachment game on in Fig. 2, which has a Nash equilibrium (Go, Attend) corre-

sponding to secure attachment as well as one (Don't Go, Ignore) corresponding to avoidant attachment.

		Adult self	
		Attend	Ignore
Inner Child	Go	**4,4**	2,2
	Don't Go	3,1	**3,3**

Fig. 2 A game with a secure and an insecure NE

In reinforcement learning one learns what action to take in order to maximise a reward signal: agents incrementally adapt their estimates of reward associated with state-action pairs based on observed outcomes following each action choice [90]. We give an overview of the adapted reinforcement learning framework for Self-attachment here. A state of the learning procedure is given by a pair of what we call an M-state and its associated Q-state. An M-state is given by a utility matrix $M \in \mathbb{R}_+^{2\times 2}$ of the Adult Self with its associated Q-state given by the ordinal representation $[M] = M/\equiv$, where the equivalence relation $\equiv$ on the set $\mathbb{R}_+^{2\times 2}$ is defined by $M \equiv N$ iff for all $i, j, i', j' \in \{1,2\}$ we have: $M_{ij} < M_{i'j'} \iff N_{ij} < N_{i'j'}$ and $M_{ij} = M_{i'j'} \iff N_{ij} = N_{i'j'}$. Thus, the Q-state can be represented as a matrix in $\{1,2,3,4\}^{2\times 2}$ with at least one entry equal to 1. The set of actions in the Q-learning are the four possible strategy profiles (Go, Attend), (Go, Ignore), (Don't Go, Attend) and (Don't Go, Ignore).

We assume that the utility matrix of the Inner Child is static and does not change throughout the course of Q-learning. The state transitions are defined as follows. If the strategy profile (Go, Attend) is played then $M_{11} \to rM_{11}$ where $r > 1$ is a fixed multiplicative reward factor. Similarly, if the strategy profile (Don't Go, Attend) is played then $M_{21} \to rM_{21}$. Otherwise, when the Adult Self plays Ignore, its utility matrix does not change. We note that when the utility matrix does change from M to M' its associated Q-state may or may not change, i.e., we can have $[M] = [M']$ or $[M] \neq [M']$. We assume the Inner Child plays reactively: if the Adult Self plays "Attend" at time t then the Inner Child plays "Go" at time $t+1$, whereas if the Adult Self plays "Ignore" at time t then the Inner Child Plays "Don't Go" at times $t+1$. The Q-value $Q([M],\beta)$ for the pair of Q-state and action $([M],\beta)$ where $\beta \in \{\text{Attend, Ignore}\}$ is updated when $M \to M'$ according to the standard Q-learning rule:

$$Q([M],\beta) \leftarrow Q([M],\beta) + \ell\left(R(M,\beta) + \delta \max_{\beta' \in S} Q([M'],\beta') - Q([M],\beta)\right)$$

where $S = \{\text{Attend, Ignore}\}$, $\ell > 0$ is the learning rate, δ is the discount factor with values $0 \leq \delta \leq 1$ and the reward R for a pair of M-state and action given by:

$$R(M,\text{Attend}) = \begin{cases} rM_{11} & \text{if (Attend, Go) is played} \\ rM_{12} & \text{if (Attend, Don't Go) is played} \end{cases}$$

and

$$R(M,\text{Ignore}) = \begin{cases} M_{11} & \text{if (Ignore, Go) is played} \\ M_{12} & \text{if (Ignore, Don't Go) is played} \end{cases}$$

The learning rate has been chosen as $\ell = \ell([M],\beta) = (n([M],\beta))^{-1}$, where $n([M],\beta)$ equals the number of times action β has been selected in Q-state $[M]$. This means that initially $\ell([M],\beta) = 1$ and subsequently $\ell([M],\beta)$ decreases with each new selection of action β in Q-state $[M]$. A softmax action selection rule [90], also called the Boltzmann probabilistic rule, is used to choose the action taken by the Adult Self according to the following probability distribution:

$$\Pr(\beta|[M]) = k^{Q([M],\beta)} \;/\; \sum_{\beta\in S} k^{Q([M],\beta)}$$

with exploration parameter $k > 1$. The greater the exploration parameter the more it is likely that, in a given Q-state, actions with higher Q-values would be selected. Thus, the reinforced Adult Self chooses actions according to a path-dependent, non-stationary stochastic process. The initial M-state M_0 is set to be the utility matrix of the Adult Self on the right in Fig. 1. The initial Q-values of a Q-state and action pair is set as follows

$$Q([M],\text{Attend}) = [M]_{21}, \qquad Q([M],\text{Ignore}) = [M]_{22}$$

i.e., it is set to the ordinal value of the Q-state $[M]$ assuming that the Inner Child plays "Don't Go".

The additional reward that reinforces the action "Attend" provides the incentive for the Adult Self to deviate with some probability from the undesirable "Ignore" action in the undesirable Nash equilibrium and to choose "Attend". It is proved mathematically in [21] that in this setting the utility matrix almost surely, i.e., with probability one, converges to the game in Fig. 1 to provide a secure attachment as a Nash equilibrium. The question is how fast is the rate of convergence.

A simulation of this framework in [21] for $r \in \{1.1, 1.3, 1.5\}$ produces Fig. 3 when $k = 1.5$ and Fig. 4 when $k = 2$ for the average number of iterations of the Q-learning algorithm for a range of values of the discount factor δ so that the utility matrix converges to give a secure attachment Nash equilibrium. As the reinforcement parameter $r > 1$ increases, the average number of iterations to yield secure attachment decreases, which can be interpreted by asserting that individuals who value the Self-attachment protocol at a higher level obtain the desired result quicker. Furthermore, the lower the discount factor δ, the quicker the convergence to secure attachment, which implies that those focused on the present and more immediate reward would see a faster path to the desired result. Finally, as the exploration parameter k increases, the speed of convergence to secure attachment decreases. In fact, for a larger value of k, the choice of "Ignore" dominates the initial rounds of the reinforcement learning because the initial Q-values of the pairs of Q-states and actions are determined by the action "Don't Go" of the Inner Child in the initial Nash equi-

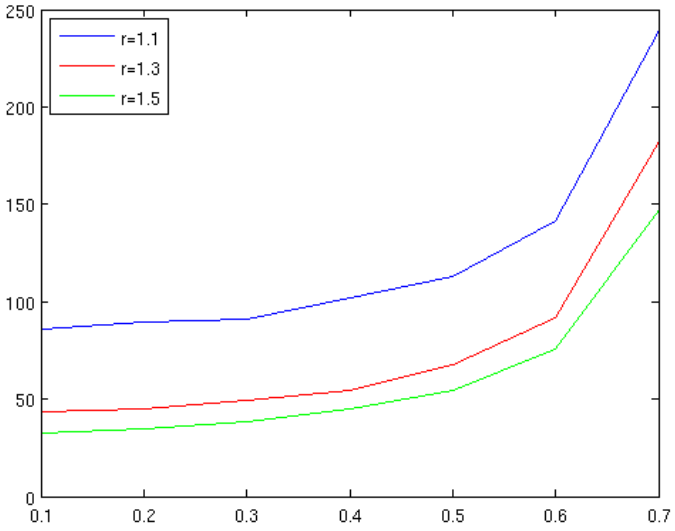

Fig. 3 Average no. of rounds to reach secure attachment for various values of the multiplicative reward factor when $k = 1.5$

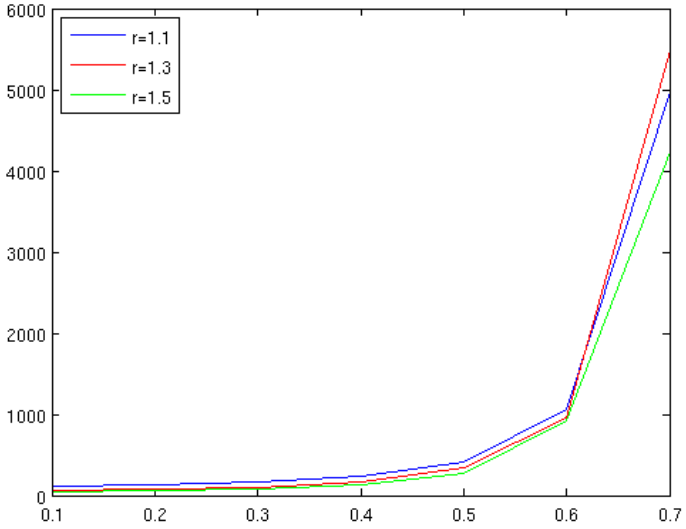

Fig. 4 Average no. of rounds to reach secure attachment for various values of the multiplicative reward factor when $k = 2$

librium $(Don't Go, Ignore)$. Therefore, larger values of k capture individuals who show resistance to therapy and are more entrenched in their original behaviour.

7 Self-attachment and Strong Patterns

In this section, we first review neural models of psychotherapy in the literature. A neural model for personality is constructed in [3], which is based on Cloninger's three-dimensional character cube [24]. It aims to model psychotherapy for individuals who are already functioning quite well but seek to improve their effectiveness. Cloninger's character cube is also used in [60] to develop a neural model for how human beings suppress or enhance certain types of behaviour. Galatzer-Levy [63] presents an outline of how non-linear dynamical systems and attractors can be used qualitatively to model the psychoanalytical process, and includes other related references in this subject. The concept of "working through" in psychoanalysis has been modelled in [96] using a Hopfield network with two weakly connected layers.

The first neural model for Self-attachment we describe here uses the notion of strong patterns in artificial neural networks, in particular Hopfield networks, an early model of energy based associative networks introduced by John Hopfield [49]. The patterns stored in such a network under the right conditions, become, with high probability, the minima of the network energy and the fixed points of the network; see below.

Attachment types and cognitive and behavioural prototypes are entrenched in the neural pathways of the brain as a result of some key repeated and strong interactions that an individual undertakes or is exposed to, which become stored patterns in the brain. In [64, p. 132-144], Lewis, Amini and Lannon emphasise that our attachment types and key emotional attitudes in relation to others are sculpted by limbic attractors as a result of repeated exposure to similar patterns of interactions in childhood, which will then profoundly impact our emotional world for the rest of our lives. They employ artificial neural networks to describe how such patterns of attitude and behaviour are developed.

Similarly, Smith, Stevens and Caldwell in [86, p. 222] proposed the Hopfield network to model cognitive and behavioural patterns considered as:

> *prototypes* deeply learned patterns of thought and social activity. In the sense developed by cognitive psychologists, prototypes are cognitive structures that preserve in memory common or typical features of a person's experience. By matching perceptions and thoughts in prototypes stored in memory, persons categorize and identify objects, form inferences and expectations, and construct predictions about the future. Prototypes thus serve an orienting function, since persons use them to guide their behaviour. In general, a person seeks the closest possible match between ongoing experience and these prototype patterns. When confronted with the unfamiliar, a person will search for the closest match to a learned prototype.

The question how to model repeatedly or strongly stored patterns in a Hopfield network has been addressed in [33, 29]. Assume we have a Hopfield network with

N neurons $i = 1,\ldots,N$ each taking values ± 1. A configuration of the network is given by $X \in \{-1,1\}^N$ with components $X_i = \pm 1$ for $1 \leq i \leq N$. Assume we have the deterministic asynchronous updating rule (i.e., with temperature $T = 0$) and zero bias in the local field at each node i.

The updating rule is:

$$\text{If } h_i \geq 0 \text{ then } 1 \leftarrow X_i \text{ otherwise } -1 \leftarrow X_i$$

where $h_i = \sum_{j=1}^{N} w_{ij} X_j$ is the local field of configuration X at i. The energy of the network (assuming zero biases at the nodes) for configuration X is given in terms of the synaptic couplings w_{ij} by

$$E(X) = -\frac{1}{2} \sum_{i,j=1}^{N} w_{ij} X_i X_j.$$

It is easy to check that if the updating rule is applied asynchronously then the energy of the network will not increase. Since there are only a finite number, in fact 2^N, configurations possible for a fixed N, it follows that with the asynchronous updating rule the network will always settle down to one of the minima of its energy landscape, which will be a fixed point of the network.

Assume we have p patterns $X^k \in \{-1,1\}^N$, with $1 \leq k \leq p$, each given by its components X_i^k for $i = 1,\ldots,N$, which are to be stored in the memory. The generalized Hebbian rule for the synaptic couplings to store these patterns is defined as follows [33, 29]:

$$w_{ij} = \frac{1}{N} \sum_{k=1}^{p} d_k X_i^k X_j^k, \tag{1}$$

for $i \neq j$ with $w_{ii} = 0$ for $1 \leq i, j \leq N$. where d_k is the *multiplicity* or *degree*, also called the *strength*, of the pattern X^k. In a standard Hopfield network we have $d_k = 1$, i.e., all patterns are *simple*. In this case, if all patterns are random and $p/N \leq 0.138$ then the network behaves like an associative network with a good memory: the p patterns become with high probability fixed points or attractors of the the network. If the network is initialised with a configuration X, then by asynchronous updating the network converges with a high probability to one of the patterns X^k for $1 \leq k \leq p$. The number 0.138 is the *retrieval capacity* of the network which can be determined both experimentally and theoretically.

If $d_k > 1$, then X^k is a *strong pattern* indicating either that the pattern has been multiply stored with the integer d_k as its multiplicity or that the pattern has been deeply stored with a high level of dopamine secretion that has reinforced the learning [100]. The corresponding attractor produced by a strong pattern in the network is called a *strong attractor*. Strong attractors are more stable than those of simple patterns and have a larger basin of attraction and and lower energy level [33]. In [29], a square law has been obtained for the retrieval capacity of a single strong pattern in the presence of simple patterns in the Hopfield network. The square law for the stability of a single neuron is deduced by a theorem of Lyapunov which generalises

the Central Limit theorem in the case we have independent but non-identically distributed random variables. Assuming that there is only a single strong pattern and all patterns are independent, one obtains for the probability that a single node of the strong pattern with degree $d \ll p$ becomes unstable:

$$\Pr_{error} \approx \frac{1}{2}\left(1 - \text{erf}(\sqrt{Nd^2/2p}\right)$$

where erf is the error function. This formula reduces to the corresponding error for the standard Hopfield network for $d = 1$ and thus we can see that for $d > 1$, the stability is increased by a factor d^2.

To establish the square law for the retrieval capacity of a whole strong pattern much more work is required. In [29], this is done by moving to the stochastic Hopfield network for a pseudo temperature $T > 0$ in which the updating rule is probabilistic. In this setting, one derives the conditions for the strong pattern to be retrievable with a non-zero probability and then one takes the limit $T \to 0$ which recovers the deterministic network. Assuming that the strong pattern has multiplicity $d > 1$ with $d \ll p$, it is shown analytically that provided p satisfies $p/N \leq 0.138d^2$, the strong pattern can still be retrieved with high probability, showing that the retrieval capacity of a strong pattern grows proportional to the square of its degree.

This square law provides us with a technique to model cognitive and behavioural proto-types as strong patterns that remain stable compared with simple patterns. In fact, it enables us to model the gist of the Self-attachment protocol, which we now describe using a simple example. Assume we store 30 copies of a generic sad face and 100,000 random images in a Hopfield network with $N = 48 \times 48 = 2304$ providing a screen of neurons regarded as pixels with values ± 1. Note that in this case we have $0.138Nd^2 = 0.138 \times 2304 \times 30^2 \approx 286,156$. Since we have a total of $100,030 < 286,156$ stored patterns, it follows by the square law that the sad face is retrievable. In fact, a simple experiment shows that with high probability any initial image will be repeatedly updated using the asynchronous rule to converge and retrieve the sad face as a fixed point. This shows that the Hopfield network is now an associative model of a sad brain which with high probability interprets any image as a sad face. We now store additionally 40 copies of a generic happy face in the same Hopfield network. In the resulting network, we have two strong patterns, the old generic sad face with degree 30 and the new generic happy face with degree 40. In the competition between these two strong pattern, the stronger one i.e., the generic happy face, wins [33]. Therefore, after initialising the network with a random pattern, with high probability, one eventually retrieves the happy face. This shows that the associated memory network which had modelled a sad brain–was biased toward retrieving the sad face– is now modelling a happy face– is biased toward retrieving the happy face.

Therefore, the process of Self-attachment therapy works according to this model by constructing, using neuroplasticity and long term potentiation, a strong optimal cognitive and behavioural pattern corresponding to each suboptimal pattern that had

previously been learned. Psychotherapy is successful once the strength of the new pattern exceeds that of the old one.

8 Neural models of Self-attachment

In this section, we will describe three neural models of the human brain for Self-attachment.

8.1 An energy based neural model with reinforcement learning

The first neural model of the human brain for Self-attachment we describe here uses Levine's pathways for emotional-cognitive decision making [62]. Levine's model contains two networks: (i) An energy based competitive *needs* network, which will be modelled here by a Hopfield network whose attractors represent the individual's competing needs that include physiological as well as higher cognitive and emotional needs, motivated by Maslow's hierarchy of needs. (ii) A network of brain regions that make either deliberate or heuristic decisions and is comprised of four connected areas: the amygdala, the OFC, ACC and DLPFC, which account for various decision rules on specific tasks as will be explained below. These four regions comprise a three-layer network, in which the vigilance threshold of the individual, represented by the ACC, determines the status of activation of each layer. The lower the vigilance threshold the quicker the alertness of the individual will be activated. The state of the needs network influences the vigilance threshold so that the winning needs become dominant to implement the corresponding decision rules.

In [31], the above framework is employed to construct a model of Self-attachment by using reinforcement learning in the form of Q-learning. This extends the results in [32] that models psychotherapy based on Mentalisation only. The needs network is represented by strong patterns in a competitive Hopfield network consisting of the two categories of (a) need for cognitive closure, which includes the six basic emotions, and (b) need for cognition, which contains Mentalisation and two subprotocols of Self-attachment named Happy-Child, aimed at increasing inner joy, and Sad-Child, aimed at reducing the negative affects of the inner child. Strong patterns with different degrees model the six basic emotions, and the three cognitive states Mentalisation, Happy-Child and Sad-Child. These patterns are represented by generic (smiley) faces in the needs network which also contains a large number of random patterns. Three identical Restricted Boltzmann Machines (RBM) [80, 38] with 17 hidden units are pre-trained to recognise the six emotions, the Mentalisation, Happy-Child and Sad-Child patterns. An RBM is a stochastic generative neural network which learns a probability distribution over the inputs it sees. They are used here to model the amygdala, the OFC and the DLPFC. These three regions together with the needs network in the brain account for various decision rules on specific

tasks and comprise a three-layer decider network, in which the vigilance threshold of the individual determines the status of activation of each layer. See Fig. 5.

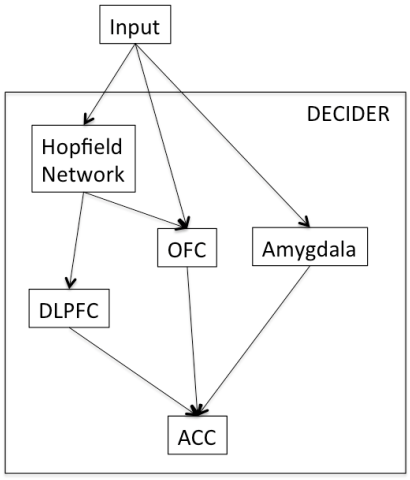

Fig. 5 The decider network consists of the DLPFC-OFC circuit for deliberate decisions on the left and the OFC-amygdala circuit which makes heuristic decisions on the right.

Suppose the Hopfield network receives a random input, modelling a random stimulus to the brain. Then, with high probability one of the strong patterns is retrieved. If the Mentalisation pattern, the Happy-Child or the Sad-Child is recalled, then the Hopfield network will send a low level vigilance threshold to the error detector (ACC), and the DLPFC-OFC circuit is chosen to generate complex decision rules. This includes practicing the protocols for Happy-Child or Sad-Child. As the secondary sensory device, the RBM in the DLPFC receives a Mentalisation signal from the Hopfield network, and categorises it into a 17-unit vector of the hidden layer. In addition, the RBM in the OFC, the primary sensory device, accounts for categorising the input pattern into another 17-unit vector. If the Hamming distance of these two generated vectors (i.e., the number of nodes they differ in) is greater than the vigilance threshold, then a mismatch occurs and the network generates a deliberative rule. Otherwise, a heuristic decision is made. However, because of the low vigilance threshold, the DLPFC- OFC circuit would most likely not make heuristic decisions in this case.

If, on the other hand, the retrieved pattern is one of the six emotion patterns, the Hopfield network will send a high-level vigilance threshold to ACC, and the OFC-amygdala circuit is selected for making decisions. Again, as the secondary sensory device, the RBM representing the OFC classifies the emotion pattern from the Hopfield network, and amygdala classifies the input pattern. The Hamming distance between the two 17 unit output vectors is compared to the high-level vigilance

threshold. A heuristic decision is made if the Hamming distance is lower than the vigilance threshold; otherwise, a deliberative decision is taken. Since the vigilance threshold is high, the OFC-amygdala circuit would most likely not make deliberate decisions in this case.

Self-attachment therapy is modelled by a Q-learning process that targets the needs network in the above framework. For simplicity, it is assumed that only six patterns are involved in the learning, namely: the three basic emotions for Angry, Sad, Happy and the three cognitive states for Mentalisation, Happy-Child and Sad-Child. The M-state of the Q-learning is given by the set of degrees or strengths of these patterns at any point in time, whereas the Q-state is given by the ordinal representation of these M-states, i.e, a list of six positive numbers between 1 and 6 that includes 1 as the lowest rank. In addition, it is assumed that there are six actions corresponding to these states. The reward table for Q-leaning is as follows:

Angry: 0 Happy: 0.3 Sad: 0

Mentalisation: 0.4 Happy-Child: 1 Sad-Child: 0.6

This means that whenever any of the six actions Angry, Happy, Sad, Mentalisation, Happy-Child, Sad-Child is selected the degree or strength of the corresponding state is increased respectively by $0, 0.3, 0, 0.4, 1.0, 6$. As can be seen in the table, the highest rewards are received for carrying out the sub-protocols for Happy-Child and Sad-Child. It is hypothesised that these sub-protocols activate the reward system of the brain, inducing dopamine, serotonin, oxytocin and vasopressin: thus these actions are more deeply learned corresponding to a relatively higher increase in their strengths in the M-state compared to Mentalisation or Happy actions.

Initially, we start with an M-state in which the pattern Angry (and/or Sad) are dominant in the needs network. As in the case of the game-theoretic model in Section 6, the Boltzmann probabilistic rule is used for choosing an action in a given Q-state. At each iteration of the algorithm, a random pattern, regarded as input, stimulates the Hopfield network and the two RBM's representing the Amygdala and OFC. The Hamming distance between the hidden layers of these two RBM's provides the measure of discrepancy and either a heuristic or deliberate decision is made. Initially, most decisions will be heuristic as a negative emotion is dominant in the needs network. As the algorithm iteratively progresses, the Q-learning process will gradually increase the strength of the more optimal patterns, i.e., Happy-Child, Sad-Child, Mentalisation and Happy. Eventually, the Happy-Child pattern becomes dominant in the needs network and as a result most decisions will be deliberate. We consider this process as modelling a successful course of Self-attachment.

In Fig. 6, the blue curve shows the average number of iterations required for a successful course of Self-attachment starting with different degrees of the initial Angry pattern. The red curve shows the average number of iterations required for the Mentalisation pattern to become dominant as a result of psychotherapy based on Mentalisation (i.e. without the sub-protocols for Happy-Child and Sad-Child). We see, as expected, that the average number of iterations required when the sub-

protocols for Happy-Child and Sad-Child are also used is significantly lower than when they are not included in the algorithm.

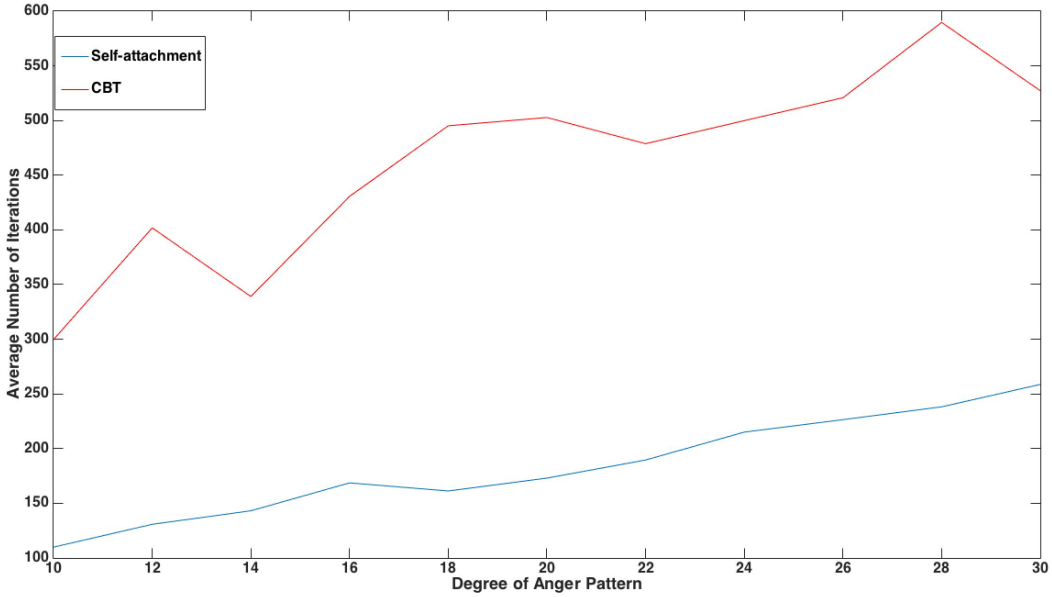

Fig. 6 Blue curve: The average number of iterations required so that, starting with the angry dominant pattern with different degrees, the Happy-Child strong pattern becomes dominant. Red curve: The average number required when only Mentalisation is used, i.e., without the self attachment protocols.

8.2 A neural model of bonding

In [22], we built on a previous model by Levine [61] concerning how emotional appraisals in the OFC can mediate between activity in neural circuits that drive stress and facilitative responses to social stimuli. Activity in stress circuitry (focused on the central nucleus of the amygdala (CeA), locus coeruleus, and the parvocellular part of the paraventricular nucleus of the hypothalamus (PVN)) results in the release of norepinephrine and corticotropin-releasing hormone (CRH, the precursor

to cortisol), while stimulation of facilitative networks (involving the magnocellular part of the PVN along with reward circuitry) leads to the release of dopamine and oxytocin.

Based on this, we hypothesised that a main effect of the Self-Attachment bonding protocols is to associate broad classes of social stimuli that have previously been conditioned as being fearful or threatening in nature with new representations of naturally-induced reward in the OFC. These new, additional reward representations are proposed to emerge as a result of the application of various activities such as directed singing with inner-child imagery.

We simulated our model computationally, using a deep belief net to model bi-directional connectivity between the OFC and basolateral amygdala (BLA) and feed-forward networks for the other pathways in the model. The pathway from the BLA to the CeA was assumed to be proportionally strengthened by the magnitude of unexpected punishments, while the pathway from ventral parts of the medial prefrontal cortex (vmPFC) to the CeA (via the intercalated cells) was proportionally strengthened by the magnitude of unexpected rewards.

Using this model we showed how, as the bonding protocols progress, OFC-dorsomedial hypothalamic pathways could increasingly facilitate natural oxytocin release from the magnocellular part of the PVN, and inhibit the release of CRH from the parvocellular part of the PVN. We additionally hypothesised that the bonding protocols would result in dopaminergic reward-prediction errors which would drive a further reduction in activity of stress circuitry via the strengthening of the inhibitory pathway from the vmPFC to the CeA.

8.3 Empathically-motivated bonding

The current focus of our work [23] is concerned with how the individual undergoing therapy might further increase motivation to apply these bonding protocols, by taking the perspective of the adult-self and attempting to enter into an empathic state with an inner-child who is conceptualised as being in distress. We build on a model by Numan [73, p.278] which considers how empathy circuitry (involving the anterior insular, anterior midcingulate cortex and medial prefrontal cortex) might stimulate a mesolimbic-ventral pallidum pathway involved in caregiving behaviour. We additionally consider circuits involved in the perception of pain in self and others, and how sufficient self-other distinction might drive such caregiving behaviour while insufficient distinction might instead result in a distress state within the individual.

9 Conclusion

After reviewing basic attachment theory and the neural basis of various attachment types, we provided compelling evidence from the literature that insecure attachment is a significant risk factor in the development of mental illness, whereas secure attachment nurtures self-regulation of emotions, vastly reducing the risk for psychological disorders. The wide ranging impact of attachment theory on psychotherapy was also looked at. We then reviewed the work on attachment objects in higher primates, children and in two different ways, namely the corresponding and compensatory pathways, among religious believers. The objective in all these cases is to use the attachment object to earn or retain secure attachment and thereby regulate strong emotions. We showed that fMRI studies indicate an overarching common denominator for bond-making, which activates the reward system in the brain, whether in romantic or maternal love or in praying. Hence, bonding with an abstract attachment object or between two individuals have neural correlates.

Based on these background results and findings, we proposed a holistic approach to Computational Psychiatry by considering an individual as an adult-self, representing the more cognitive aspects, and an inner child, representing the more affective aspects of the individual. Self-attachment uses a self-administrable protocol to create a secure attachment object, represented as the adult-self, for the inner child within an individual. The adult-self is to become a "good enough" parent for the inner child who is to be freed from attachment insecurities and grow emotionally.

We presented several computational models for Self-attachment: (i) a game-theoretic model based on reinforcement learning, (ii) an energy based competitive neural network of needs, which is reinforced for optimal decision making using the Amygdala, OFC and DLPFC represented by RBM's, (iii) a neural model for bond-making in Self-attachment which uses a model for how emotional appraisals in the OFC can mediate between activity in neural circuits that drive stress and facilitative responses to social stimuli, and, (iv) a model for empathically-motivated bonding.

What general result can be deduced from this work for psychiatrists? In a few words, we need to consider attachment theory and early development as a central/starting point in psychiatry and psychotherapy. Self-attachment therapy is an attempt to provide a holistic and attachment-centric approach to psychotherapy.

As for computationalists, we can conclude that computational modelling of Self-attachment (and indeed attachment in general) is fertile ground. Such work can help us to understand and develop more fully the therapy going forwards.

Acknowledgements I would like to thank David Cittern for reading the article and providing me with various suggestions.

References

1. J. S. Abramowitz, B. J. Deacon, and S. PH. Whiteside. *Exposure therapy for anxiety: Principles and practice*. Guilford Press, 2012.
2. M. D. S. Ainsworth, M. C. Blehar, E. Waters, and S. N. Wall. *Patterns of Attachment: A Psychological Study of the Strange Situation*. Psychology Press, 2015.
3. A. M. Aleksandrowicz and D. Levine. Neural dynamics of psychotherapy: what modeling might tell us about us. *Neural Netw*, 18(5-6):639–45, 2005.
4. J. G. Allen, P. Fonagy, and A. W. Bateman. *Mentalizing in Clinical Practice*. American psychiatric Publishing, 2008.
5. A. Aron, H. Fisher, D. J. Mashek, G. Strong, H. Li, and L. L. Brown. Reward, motivation, and emotion systems associated with early-stage intense romantic love. *Journal of neurophysiology*, 94(1):327–337, 2005.
6. A. Bartels and S. Zeki. The neural basis of romantic love. *Neuroreport*, 11(17):3829–3834, 2000.
7. A. Bartels and S. Zeki. The neural correlates of maternal and romantic love. *NeuroImage*, 21:1155–1166, 2004.
8. C. D. Batson, P. Schoenrade, and W. L. Ventis. *Religion and the Individual: A Social-Psychological Perspective*. Oxford, 1993.
9. D. Bergen. The role of pretend play in children's cognitive development. *Early Childhood Research & Practice*, 4(1), 2002.
10. A. Birgegard and P. Granqvist. The correspondence between attachment to parents and God: Three experiments using sub- liminal separation cues. *Personality and Social Psychology Bulletin*, 30:1122–1135, 2004.
11. B. Ghobary Bonab, M. Miner, and M. T. Proctor. Attachment to God in Islamic spirituality. *Journal of Muslim Mental Health*, 7(2), 2013.
12. J. Bowlby. The growth of independence in the young child. *Royal Society of Health Journal*, 76:587–591, 1956.
13. J. Bowlby. The nature of the child's s tie to his mother. *International Journal of Psycho-Analysis*, 39:350–373, 1958.
14. J. Bowlby. *The Making and Breaking of Affectional Bonds*. Routledge, 1989.
15. J. Bowlby. *Attachment: Volume One of the Attachment and Loss Trilogy*. Pimlico, second revised edition, 1997.
16. L. Buono, R. Chaua, G. Lewis, N. Madras, M. Pugh, L. Rossi, and T. Wi-telski. Mathematical models of mother/child attachment. Problem proposed by L. Atkinson, J. Hunter and B. Lancee at the Fields-MITACS Industrial Problem Solving Workshop August, 2006.
17. J. P. Capitanio. Behavioral pathology. In G. Mitchell and J. Erwin, editors, *Comparative Primate Biology*, volume Volume 2A: Behavior, Conservation, and Ecology, pages 411–454. Alan R. L iss, 1986.
18. D. Capps, editor. *Freud and Freudians on Religion: A Reader*. Yale University Press, 2001.
19. J. Cassidy and P. R. Shaver, editors. *Handbook of Attachment*. Guilford, 1999.
20. D. Cittern and A. Edalat. Reinforcement learning for Nash equilibrium generation. In *Proceedings of Autonomous Agents and Multiagent Systems (AAMAS)*, 2015.
21. D. Cittern and A. Edalat. Reinforcement learning for nash equilibrium generation. In *Proceedings of Autonomous Agents and Multiagent Systems (AAMAS)*, 2015. Extended Abstract.
22. D. Cittern and A. Edalat. Towards a neural model of bonding in self-attachment. In *Neural Networks (IJCNN), 2015 International Joint Conference on*, pages 1–8. IEEE, 2015.
23. D. Cittern and A. Edalat. A neural model of empathic states in attachment-based psychotherapy. pre-print, 2016.
24. C. R. Cloninger. A new conceptual paradigm from genetics and psychobiology for the science of mental health. *Aust N Z J Psychiatry.*, 32(2):174–86, 1999.
25. R. J. Corsini. *Role Playing in Psychotherapy*. AldineTransaction, 2011.
26. L. Cozolino. *The Neuroscience of Human Relationships*. W. W. Norton, 2006.

27. L. Cozolino. *The Neuroscience of Psychotherapy: Healing the Social Brain*. W. W. Norton, second edition edition, 2010.
28. F. CP. Van der Horst, H. A. LeRoy, and R. Van der Veer. when strangers meet: John Bowlby and Harry Harlow on attachment behavior. *Integrative Psychological and Behavioral Science*, 42(4):370–388, 2008.
29. A. Edalat. Capacity of strong attractor patterns to model behavioural and cognitive prototypes. In C.J.C. Burges, L. Bottou, M. Welling, Z. Ghahramani, and K.Q. Weinberger, editors, *Advances in Neural Information Processing Systems (NIPS) 26*. ACM, 2013.
30. A. Edalat. Self-attachment: A new and integrative psychotherapy. Talk at the Institute of Psychiatry, London, 02-05-2013, 2013.
31. A. Edalat. Introduction to self-attachment and its neural basis. In *2015 International Joint Conference on Neural Networks, IJCNN 2015, Killarney, Ireland, July 12-17, 2015*, pages 1–8, 2015.
32. A. Edalat and Z. Lin. A neural model of mentalization/mindfulness based psychotherapy. In *Neural Networks (IJCNN), 2014 International Joint Conference on*, pages 2743–2751. IEEE, 2014.
33. A. Edalat and F. Mancinelli. Strong attractors of Hopfield neural networks to model attachment types and behavioural patterns. In *IJCNN 2013 Conference Proceedings*. IEEE, August 2013.
34. R. N. Emde. Development terminable and interminable: II. recent psychoanalytic theory and therapeutic considerations. *The International Journal of Psychoanalysis*, 1988.
35. C. J. Falconer, M. Slater M, A. Rovira, J. A. King, P. Gilbert, and A. Antley. Embodying compassion: a virtual reality paradigm for overcoming excessive self-criticism. *PLoS ONE*, 9(11), 2014.
36. C. J. Falconer, A. Rovira, J. A. King, P. Gilbert, A. Antley, P. Fearon, N. Ralph, and C. R. Brewin M. Slater. Embodying self-compassion within virtual reality and its effects on patients with depression. *British Journal of Psychiatry*, 2 (1):74–80, 2016.
37. T. Field, M. Hernandez-Reif, M. Diego, S. Schanberg, and C. Kuhn. Cortisol decreases and serotonin and dopamine increase following massage therapy. *International Journal of Neuroscience*, 115(10):1397–1413, 2005.
38. A. Fischer and C. Igel. Training restricted boltzmann machines: an introduction. *Pattern Recognition*, 47(1):25–39, 2014.
39. P. Fonagy. *Attachment Theory and Psychoanalysis*. Other Press, 2001.
40. J. D. Ford. Neurobiological and developmental research. *Treating complex traumatic stress disorders: An evidence-based guide*, pages 31–58, 2009.
41. S. Freud. *The Future of an Illusion*. Martino Fine Books, 2011. First published in 1928.
42. D. Fudenberg and J. Tirole. *Game Theory*. MIT Press, 1991.
43. C. George, N. Kaplan, and M. Main. The adult attachment interview. Unpublished manuscript, University of California at Berkeley, 1985.
44. P. Gilbert. *Compassion: Conceptualisations, research and use in psychotherapy*. Routledge, 2004.
45. K. R. Ginsburg. The importance of play in promoting healthy child development and maintaining strong parent-child bonds. *Pediatrics*, 119(1):182–191, 2007.
46. P. Granqvist, T. Ivarsson, A. G. Broberg, and B. Hagekull. Examining relations between attachment, religiosity, and new age spirituality using the adult attachment interview. *Developmental Psychology*, pages 590–601, 2007.
47. P. L. Granqvist, M. Mikulincer, and P. R. Shaver. Religion as attachment: normative processes and individual differences. *Pers Soc Psychol Rev*, 2010.
48. H. F. Harlow. The nature of love. *American Psychologist*, pages 673–685, 1958.
49. J. J. Hopfield. Neural networks and physical systems with emergent collective computational abilities. *Proceedings of the National Academy of Science, USA*, 79:2554–2558, 1982.
50. W. James. *The varieties of religious experience*. Harvard University Press, 1985.
51. K. J. Jeffries, J. B. Fritz, and A. R. Braun. Words in melody: an H215o PET study of brain activation during singing and speaking. *Neuroreport*, 14(5):749–754, 2003.

52. G. D. Kaufman. *The Theological Imagination: Constructing the Concept of God*. Westminster John Knox Press, 1981.
53. B. King-Casas, C. Sharp, L. Lomax-Bream, T. Lohrenz, P. Fonagy, and P. R. Montague. The rupture and repair of cooperation in borderline personality disorder. *Science*, 321(5890):806–810, 2008.
54. L. Kirkpatrick. Attachment and religious represenations and behaviour. In J. Cassidy and P. R. Shaver, editors, *Handbook of Attachment*, pages 803–822. Guilford, 1999.
55. L. A. Kirkpatrick. *Attachment, evolution, and the psychology of religion*. Guilford, 2005.
56. L. A. Kirkpatrick and P. R. Shaver. Attachment theory and religion: Childhood attachments, religious beliefs, and conver- sion. *Journal for the Scientific Study of Religion*, 29:315–334, 1990.
57. L. A. Kirkpatrick, D. J. Shillito, and S. L. Kellas. Loneliness, social support, and perceived relationships with God. *Journal of Social and Personal Relationships*, pages 13–22, 1999.
58. B. Kleber, N. Birbaumer, R. Veit, T. Trevorrow, and M. Lotze. Overt and imagined singing of an Italian aria. *Neuroimage*, 36(3):889–900, 2007.
59. H. Kohut, editor. *How Does Analysis Cure?* University of Chicago Press, 1984.
60. D. Levine. Angels, devils, and censors in the brain. *ComPlexus*, 2(1):35–59, 2005.
61. D. Levine. Neural networks of human nature and nurture. *Avances en Psicología Latinoamericana, junio, año/vol. 26, número 001 Universidad del Rosario Bogotá, Colombia*, 2008.
62. D. Levine. Brain pathways for cognitive-emotional decision making in the human animal. *Neural Networks*, 22:286–293, 2009.
63. R. M. Galatzer Levy. Good vibration s: Analytic process as coupled oscillations. *The International Journal of Psychoanalysis*, 90(5):983 – 1007, 2009.
64. T. Lewis, F. Amini, and R. Richard. *A General Theory of Love*. Vintage, 2000.
65. C. J. Litt. Theories of transitional object attachment: An overview. *International Journal of Behavioral Development*, 9(3):383–399, 1986.
66. M. Main. Attachment theory: Eighteen points. In J. Cassidy and P. R. Shaver, editors, *Handbook of Attachment*, pages 845–887. Guilford, 1999.
67. M. Main and J. Solomom. Procedures for identifying infants as disorganized/disoriented during the Ainsworth strange situation. In *Attachment in the Preschool Years: Theory, Research, and Intervention*, page 12160. University of Chicago Press, 1990.
68. W. W. Meissner. *Psychoanalysis and religious experience*. Yale University Press, 1986.
69. M. Mikulincer and P. R. Shaver. *Attachment in adulthood: structure, dynamics, and change*. Guilford, 2007.
70. M. Mikulincer and P. R. Shaver. An attachment perspective on psychopathology. *World Psychiatry*, 11(1):11–15, 2012.
71. P. R. Montague, R. J. Dolan, K. J. Friston, and P. Dayan. Computational psychiatry. *Trends in Cognitive Sciences*, 16(5):306, 2012.
72. C. Q. Murcia, S. Bongard, and G. Kreutz. Emotional and neurohumoral responses to dancing tango argentino the effects of music and partner. *Music and Medicine*, 1(1):14–21, 2009.
73. M. Numan. *Neurobiology of social behavior: toward an understanding of the prosocial and antisocial brain*. Academic Press, 2014.
74. J. H. Obegi and E. Berant, editors. *Attachment Theory and Research in Clinical Work with Adults*. Guilford Press, 2009.
75. J. D L. Pearsona1, D. A. Cohna, P. A. Cowana, and C. P. Cowan. Earned- and continuous-security in adult attachment: Relation to depressive symptomatology and parenting style. *Development and Psychopathology*, 6(2):359–373, 2008.
76. L. I. Perlovsky. *Neural dynamic logic of consciousness: the knowledge instinct*. Springer, 2007.
77. D. Purves, G. Augustine, D. Fitzpatrick, W. Hall, A. LaMantia, J. McNamara, and S. M. Williams, editors. *Neuroscience*. Sinauer Associate, third edition, 2004.
78. M. ME. Riem, M. J. Bakermans-Kranenburg, M. H. van IJzendoorn, D. Out, and S. ARB. Rombouts. Attachment in the brain: adult attachment representations predict amygdala and behavioral responses to infant crying. *Attachment & human development*, 14(6):533–551, 2012.

79. M. R. Roesch, D. J. Calu, and G. Schoenbaum. Dopamine neurons encode the better option in rats deciding between differently delayed or sized rewards. *Nature neuroscience*, 10(12):1615–1624, 2007.
80. R. Salakhutdinov, A. Mnih, and G. Hinton. Restricted Boltzmann machines for collaborative filtering. In *Proceedings of the 24th international conference on Machine learning*, pages 791–798, 2007.
81. V. N. Salimpoor, M. Benovoy, K. Larcher, and A. Dagher andR. J. Zatorre. Anatomically distinct dopamine release during anticipation and experience of peak emotion to music. *Nature neuroscience*, 14(2):257–262, 2011.
82. U. Schjoedt. It's a brain puzzle, 2012. http://www.theeuropean-magazine.com/649-schj-dt-uffe/650-the-neuroscience-of-prayer. Retrieved on 01-12-2016.
83. U. Schjoedt, H. Stjoedkilde-Joergensen, A. W. Geertz, and A. Roepstorff. Rewarding prayers. *Neurosci Lett.*, 443(3):165–8, October 2008.
84. A. N. Schore. *Affect Dysregulation and Disorders of the Self*. W. W. Norton, 2003.
85. A. N. Schore. *The Science of the Art of Psychotherapy*. Norton, 2012.
86. T. S. Smith, G. T. Stevens, and S. Caldwell. The familiar and the strange: Hopfield network models for prototype-entrained attachment-mediated neurophysiology. In Thomas S. (Ed) Franks, David D. (Ed); Smith, editor, *Mind, brain, and society: Toward a neurosociology of emotion*, pages 213–245. Elsevier Science/JAI Press, 1999.
87. L. A. Sroufe. Attachment and development: A prospective, longitudinal study from birth to adulthood. *Attachment & Human Development ,*, 7(4):49 367, 2005.
88. I. Stewart and V. Joines. *TA today: A new introduction to transactional analysis*. Lifespace Pub., 1987.
89. A. Storr. *Solitude*. Flamingo, 1988.
90. R. S. Sutton and A. G. Barto. *Reinforcement Learning: An Introduction*. MIT Press, 1998.
91. L. Thims. *Human Chemistry*, volume two. Lulu.com, 2007.
92. C. Ullman. Change of mind, change of heart: Some cognitive and emotional antecedents of religious conversion. *Journal of Personality and Social Psychology*, 42:183–192, 1982.
93. M. H. Van Ijzendoorn and P. M. Kroonenberg. Cross-cultural patterns of attachment: A meta-analysis of the strange situation. *Child Development*, (1988.
94. M. H. Van Ijzendoorn and A. Sagi. Corss-cultural patterns of attachment: Universal and contextual dimensions. In J. Cassidy and P. R. Shaver, editors, *Handbook of Attachment*, pages 713–734. Guilford, 1999.
95. D. Wallin. *Attachment in Psychotherapy*. Guilford Press, 2007.
96. R. S. Wedemann, R. Donangelo, and L. A. de Carvalh. Generalized memory associativity in a network model for the neuroses. *Chaos: An Interdisciplinary Journal of Nonlinear Science*, 19(1), 2009.
97. D. Winnicott. Transitional objects and transitional phenomena. *International Journal of Psycho-Analysis*, 34:89–97, 1953.
98. D. Winnicott. *Playing and Reality*. Basic Books, 1971.
99. D. Winnicott and M. M. R. Khan. *The maturational processes and the facilitating environment: Studies in the theory of emotional development*. Hogarth Press London, 1965.
100. R. A. Wise. Dopamine, learning and motivation. *Nature Reviews Neuroscience*, 5:483–494, 2004.
101. F. Wörgötter and B. Porr. Temporal sequence learning, prediction, and control: a review of different models and their relation to biological mechanisms. *Neural Computation*, 17(2):245–319, 2005.
102. J. E. Young, J. S. Klosko, and M. E. Weishaar. *Schema Therapy: A Practitioner's Guide*. Guildford Press, 2006.