SN Soc Sci (2023) 3:124
https://doi.org/10.1007/s43545-023-00707-6

REVIEW PAPER

Complexity theory as an exploratory paradigm: can scientific inquiry effectively measure individual's challenging behaviour in a non-linear way

Krista Tomas[1]

Received: 27 September 2022 / Accepted: 26 June 2023 / Published online: 22 July 2023

Abstract

Theoretical constructs to explore neurocognitive management of challenging behaviour in young people are inherently fraught with the difficulty of what exactly is to be measured that is acceptably benchmarked against standard mechanistic scientific inquiry. Indeed, this identifies the potential for a new scientific paradigm to be developed that explains the links between complex brain systems and functions, the development of the mind and adolescent challenging behaviour. The imperative lies in overcoming the strictly linear nature of some of the current scientific inquiry methods embracing instead, tools that can measure the non-linear, unexpected and emergent features of change. These changes are elicited through the interaction of the brain and human environments, sometimes manifesting in chaotic and challenging behaviour. The objective of this article is to explore the subtleties of complexity theory, to determine an essential lead to a non-linear way of measuring challenging behaviour in adolescents. The brain is a complex system and CT provides, here, the framework for understanding the dynamic and often non-linear neural activity that shifts in response to changes in an individual's environment. I pose the question; Exploring CT as an underpinning theoretical framework, is it demonstrated that there are methods of measuring the non-linearity of an individual's challenging behaviour, in a way that meets the expectations of sound scientific inquiry? The method used is an exploratory review and is addressed in two parts. The first is how to explain challenging behaviour in a neuro-informed state of complexity and the second is whether it is possible to use Complexity Theory as an exploratory framework for determining the non-linear characteristics of challenging behaviour. The article concludes with suggestions that Complexity Theory is an evolving theoretical construct primed to advance a more in-depth understanding of the non-linearity of challenging behaviour. As such, Complexity Theory has the potential for exploring a new paradigm of scientific inquiry.

Keywords Complexity theory (CT) · Challenging behaviour · Non-linearity · Exploratory paradigm · Mind/brain states

---

Extended author information available on the last page of the article

Introduction

Models of scientific inquiry approach research both descriptively and mechanistically. To some, this means identifying the difference between what is observable and repeatable. To others, it is a differentiation between correlation and causation or between description and the how and what is described, that is, the mechanics. It is suggested that the lines can blur between descriptive and mechanistic inquiry (Casadevall and Fang 2009). However, fundamentally it is accepted by researchers that sound and ethical research should invoke "the three pillars of good science—Repeatability, Refutability and Predictability" (Tranquillo 2019, p. 23). These principles are said to underpin the testing of evidence. The question is when researching brain function and development of the mind regarding emotions and subsequent chaotic behaviour in young people, are these principles sustainable or an appropriate way of measuring the impact of challenging behaviour in the real world. If viewed through the lens of the brain as a complex system with underlying complexity that is not always predictable, how is it possible to explain or measure changes that do not always occur in a linear way?

To understand a complex system Tranquillo (2019) suggests that the application in research of mathematical formulas and statistical rules from a fundamentally Newtonian perspective has been superseded by complexity in all systems. Furthermore, complexity has exposed the limitations of the three pillars of scientific inquiry; however, the author errs on the side of caution in attributing non-linear analysis in recent computational mathematics and diagnostic tools. Tranquillo (2019) suggests there is a gap not addressed in the current scientific inquiry that fails to give consideration to the long-term impacts of dynamic change. This gap thwarts the exact measurement of non-linearity in complex systems. Moreover, he reflects on complexity in the context of the layered interconnectedness or "patterns in systems"(p. 24), suggesting these systemic layers defy normal parameters of inquiry. Therefore, to understand complex systems only an interdisciplinary approach can speak to the diversity in how the real-world works. Tranquillo admits to an incomplete attempt at making connections between theoretical and analytical constructs, suggesting that intrinsically "deterministic" (p. 22) modelling continues to support mechanistic lines of inquiry. In addition, he suggests there are traps in over-simplifying the rules of inquiry that effectively undermine the concept of complexity, its unpredictability and diversity. He suggests unpredictability and diversity are context-driven and time and space derived, with multiple variables dictating whether changes will be predictable, repeatable, or causally ill-defined and chaotic. The crossover between complexity and chaos renders normal methods of inquiry incomplete (Tranquillo 2019).

In contrast to views that modelling has not addressed non-linearity, Boroujeni et al. (2019) have recently used encephalograms (hereafter EEG) in the diagnosis of Attention Deficit Hyperactivity Disorder (hereafter ADHD) tracking the "highly non-linear dynamic system *of the brain, in its capacity to reveal* chaotic behaviour" (p. 260). By mapping differences in "alpha and beta bands" (p. 260) between children with ADHD and those children with apparent normal behaviour presentation, they have been able to demonstrate the non-linear patterning that distinguishes chaotic and erratic brain signals from normal non-chaotic sensory anticipatory and motor function. Worth noting and in apparent juxtaposition, Boroujeni et al. (2019) discuss dynamic differences in brain wave activity in ADHD at the same time as they continue to identify ADHD as a "behavioural disorder…*or* disease" (p. 260). That is, they are essentially categorising ADHD within a psychological or medical framework without explaining how this connects with current neuroscientific thinking that identifies ADHD as a neurological spectrum disorder. Behaviour is just part of diagnosis of ADHD. Neither is the condition now commonly viewed as a disease (ADHD Australia 2019).

At the same time as they use medicalised terminology to reference ADHD diagnosis, Boroujeni et al. (2019) assign chaos theory to EEG signal analysis, to underpin an understanding of the difference in brain activity between children with normal behaviour presentation and those with ADHD. This demonstrates a transition already exists between classic medical modelling and established EEG technology that highlights abnormal neurological activity for which chaos theory is an apt descriptor. This appears to be an inductive process and perhaps one step ahead of what Tranquillo (2019) suggests is Newtonian linearity. More importantly, chaos theory, in its exposure of the non-linearity of activities in systems, is increasingly embraced by more scientific disciplines as an integral element of complexity theory (henceforth CT) (Hormazabal et al. 2021; Rickles et al. 2007). So what do we understand by complexity theory?

Byrne (1998) suggests the main concern in CT is to understand the interrelationships between the macro (the 'real' system under investigation) and the micro (the changes occurring in a split-second time and space that can drastically alter that system). That is, those small, powerful, and significant shifts in the energy of change over time contribute substantively to "big differences" (p. 18) in the lived experience of reality. He refers to complexity as "a scientific and inductive idea" (p. 170) that reveals, over time, an element of "randomness" (p. 174) in change that negates predictability. Nor can change be refuted or replicated in precisely the same context that it started from. This is not to say he is referring specifically to neurological systems, as his work historically pre-dates the expanded views of the neuroscientific world; however, he does refer to the emergence of ideas from chaos theory. Such ideas signify the "changes which cannot be fitted into a simple linear law" (p. 5) and that may indeed reflect a move toward understanding the uncertainty in cause and effect that is so much a part of complex systems.

This is particularly relevant when discussing the brain as a complex system. For example, it is generally accepted by neuroscientists that challenging behaviour is triggered by an emotional response in multiple areas of the brain; however, there is difficulty in agreeing on precisely what emotional response is registered where in the brain (Cabanac 2002; James 2020; Johnson and de Haan 2015; National Scientific Council on the developing child 2020; Siegel 2020). Moreover, a question might be asked about what key differences in an individual's response to chaotic environments makes one moment for an individual a very different experience for another. That is, individual responses that precipitate the difference between an interconnected and integrated brain system or one that is chaotic and challenged (Siegel 2020; Tranquillo 2019).

There is, however, a general neuroscientific agreement that emotion is the key to understanding the multi-layered process of complex states of reality. That is, emotions are subjective and characterized by a variety of physical, physiological, and psychological reactions to variations in the environments an individual engages with (Anderson 2009; Baars and Gage 2010; Cacioppo et al. 2013; Johnson and de Haan 2015; Siegel 2020). The abrupt transition that can be made from one state of reality to another raises issues that suggest there is a subtle exchange of energy taking place in individuals that may describe the existence of non-linearity of a complexity kind; however, whether CT is enough to resolve the issue of measurement of these subtleties is of itself, an invitation to an exploratory approach to complexity.

Despite differences between neuroscientists, there is consensus that a well-developed brain functions in a state of interconnectedness and integration within an individual and is driven by emotional responses to multiple internal and external environmental demands. Therefore, the key to self-regulation for children lies in how well interconnectedness and integration are sustained (Badcock et al. 2019; Buckner and DiNicola 2019; Johnson and de Haan 2015; Siegel 2020; Sporns 2013).

In contrast, challenging behaviour occurs when complexity in the inner and outer world of the individual is chaotic, that is, due either to trauma occurring as a result of catastrophic events or under conditions of prolonged and repeated stress. This causes chronic disruption to the normal, functional state dependence of the brain. For children presenting with chronic challenging behaviour, self-regulation is dependent on how early in an individual's life an appropriate neuro-informed intervention can facilitate positive change (Ochsner and Gross 2008; Perry 2020; Siegel 2020). Moreover, the notion that such behaviour is undesirable or exhibiting "wilful defiance… manipulation … lax parenting … *or* a diagnosis" (Delahooke 2019, p. 3) underpins a proliferation of behaviour modification approaches to correcting the behaviour, without the recognition that children may be imprisoned in conditioned neural reactions to stress (Delahooke 2019). In keeping with constant shifts in perspectives or understanding, neuroscientists look at the brain and behaviour using multiple measurement tools.

Neuroscientists use technical, practical formulaic and observational approaches to explain brain function and structure under conditions of stress (Baars and Gage 2010; Giedd 2004; Haas et al. 2018; Headway 2023; Isquith et al. 2015; Zelazo 2015). This implies that answers to the interaction of brain function, emotions and behaviour are more appropriately gained from empirical data than from theory or logic; however, if exponents of CT suggest it is necessary to create data from non-linear scenarios, then an interdisciplinary approach to understanding precisely what is happening at any point in time, is a good place to start searching for a more inclusive method of measuring complexity. This may require dispensing with terms like dysfunctional since they are representative of medical models that seek to remedy behaviour that is perceived as "negative *or* abnormal" (Everaerta et al. 2020).

By attaching a "dysfunctional" (Rudlin 2022, p. 1) label to emotional and behavioural dysregulation and not recognising the complexity within each child's mind/brain function, we are failing them in multiple ways. Moreover, if we continue to view CT as an antithetical paradigm to excellent scientific inquiry, we deny the opportunity to develop new models that allow the freedom to explore the complexity that is intrinsic to children with challenging behaviour.

Exploring CT as an underpinning theoretical framework, is it demonstrated that there are methods of measuring the non-linearity of an individual's challenging behaviour, in a way that meets the expectations of sound scientific inquiry?

The method here is an exploratory review and seeks to determine whether it is possible to use CT as the construct to unravel the lived experiences of children who present with challenging behaviour. To explore CT in this way the theory must be set against the multidimensional nature of mind/brain function, in the context of the complexities this presents. Furthermore, a starting point for this exploration in regard to challenging behaviour, requires an understanding of the "connected social brain *that is*…the social connectome" (Maliske and Kanske 2022, p. 2) and how flexible or inflexible this is when responding to increasingly dynamic and complex environments. This section will be in two parts.

- Viewing behaviour through a neuro-informed complexity lens.
- CT as an exploratory paradigm?

Viewing behaviour through a neuro-informed complexity lens

Prior to defining the brain as a complex system, it is prudent to identify what is actually meant by complex systems. Complex systems are those systems with structures and functions that are fluid and dynamic, coming together as an interacting whole and creating emergent and unpredictable features that do not quite fit with current methods of rigorous inquiry. According to Tranquillo (2019), a key feature of complex systems is that the interconnectedness of these parts gives rise to the complexity that expresses non-linearity. Byrne (1998) proposes that non-linearity is reflective of real-world environments that cannot be explained in a strictly mechanistic or predictable way. Moreover, non-linear events are those on trajectories of unpredictability and chaotic change.

Ladyman and Wiesner (2020) expand on these perspectives suggesting that complex systems are both dynamic and adaptive. In addition to concepts of non-linearity, chaos, emergence, differentiated and undifferentiated functions, they suggest four key features that are fundamental to an understanding of the adaptability of complex systems. Firstly, "non-equilibrium" (p. 74) which is understood to be the continuous changes a system undergoes that can tip the system into fluctuating states of equilibrium or disequilibrium. Second, the resilience of a complex system is exhibited in a level of "robustness" (p. 75), that is an ability to withstand the shocks that may disrupt the normal functionality of that system. Third, the systems robustness facilitates a process of "self-organisation" (p. 76) in the absence of centralized organisational control. Finally, to expedite balanced functionality, robustness and self-organisation a system depends on an information feedback loop that continually updates the outflow of information back to inflow in the process of behavioural adjustment and clarification. When considering a perspective on the brain states of adolescents exhibiting challenging behaviour, in light of these features the questions might include how relevant these features are to predict normal adolescent adjustment to stresses and events in their lives. In contrast, can these features be guaranteed to predict normalized outcomes for adolescents under conditions of prolonged stress or trauma? For example, is there evidence that their brains are capable of the robustness necessary to return brain function to normality from prolonged states of stress?

If we see the brain as essentially adaptive and hierarchically capable of predicting internally the uncertainty of external information that is disruptive or chaotic, then it is perhaps possible that through the feedback loop, a neural adjustment occurs that responds to stressful social or psychological environments with recognition of future sensitivity to triggers. Indeed Badcock et al. (2019) suggested exactly this in their development of modelling that demonstrates, under conditions of threat or stress, how "changes in top-down expectations … produce social withdrawal and increase*d* attention to social stimuli" (p. 1341) resulting in ultimate re-engagement with the social environment once the threat has passed. On the other hand, the brain can adapt into a chronic or "maladaptive" (p. 1341) state wherever prolonged stress has been the pattern in adolescents lives. Interestingly, it has been found that some adolescents may develop a chronic depressive response while others do not. In the former, the authors identify clinical depression in adolescence as indicative of "functional deficits" in the lower limbic parts of the brain that are to do with emotional control (p. 1341).

Of course, there is the possibility that state dependence of the brain that is either temporarily out of equilibrium or clinically maladjusted, may through robustness and self-adjustment re-emerge into a state of self-organisation as identified by Ladyman and Wiesner (2020). Indeed, Siegel (2020) has suggested that the overarching drive of the brain as a complex system is "integration as it moves towards optimizing self-organisation" (p. 474). Integration is identified as "the mind's process of linking differentiated parts…*namely* information processing… into a functional whole" (p. 506). Chaos and rigidity are in opposition to this process. Thus we may view challenging behaviour as reflecting a maladjusted brain state that can either stay unintegrated in a state of chaos or rigidity or, with the aid of neuroplasticity and "networks of social connections as well as by specific practices that develop the mind's attention, awareness, compassion and kindness" (p. 477) ultimately return to normal neuronal functioning; however, as the author suggests, a multi-theoretical approach to such intervention is necessary. If this is a mind process, as opposed to a strictly physiological or anatomical process, what is meant by the mind?

Siegel and Drulis (2023) describe the mind as emerging from a flow of energy through the ebbing and flowing of information processing through internal neural activity and external environmental information and impressions. They propose invoking the mathematical principles of systems theory to suggest how self-organisation and emergence in brain function are intertwined with "four facets of mind… that is…subjective experience, the felt texture of life, consciousness, our capacity to be aware; and information processing" (p. 6). Through the use of modelling known as Interpersonal Neurobiology (hereafter, IPNB) they explain the mind as dependent on the "energy flow" (p. 7) that comes from neural function and brain physiology within and communications in relationships and environments without. Here we not only have perspectives on non-linearity and emergence but on the adaptability of the brain as a complex system to self-adjust and return to integration. This process of integration epitomizes complexity in a complex system. For example, Siegel (2020) refers to “integration that recruits multiple layers of *neuronal* circuits” (p. 455) to develop and facilitate a world view and prompt responses to internal and external information. The functions of the hippocampus that “links mental representations to emotional appraisal centers, and even participates in mapping our social worlds” (p. 454) is but one case in point. This is illustrated in the example below which provides early attempts to measure the awesome complexity of brain function and mind based on parameters of social indicators.

The hippocampus is a complex part of the brain that sits below the cortex of the brain on the border of the limbic region. It is currently known that some hippocampal activity can induce neuroplastic changes that influence other parts of the brain and effect changes in the hippocampus itself (Sanna et al. 2022). In line with neuroplasticity the hippocampus is also responsible for some forms of “memory and learning” (Anand and Dhikav 2012, p. 239). Wang et al. (2016) investigated “hippocampal atrophy” (p. 3757) in adolescents experiencing prolonged poverty, using human neuroimaging studies.They found that those with “high self-esteem” (p. 3763) appeared to demonstrate resistance to atrophy. An assumption was made that their brains had adapted more effectively to resist- or adjust to- the worst affects of prolonged exposure to poverty. Interestingly, while self-esteem is considered a “psycho-social” (Barbot et al. 2019, p. 436) milestone for adolescents, neuroscience research has also equated its development with varying neural domains and functions, for example, in relation to self-awareness in the Medial Pre-frontal Cortex (mPFC) and in relation to cognition, which is suggested to emerge from the frontal lobes of the cortex (van der Aar et al. 2019). Both these perspectives fit with Schafer and Schiller (2018) view that the hippocampus plays a role of “cognitive mapper” (p. 476) that is using the mental images to recall, acquire and interpret information to assist understanding and in navigating internal and external environments. According to Siegel (2020) these mental images contribute to a process of “personal, subjective experiences, awareness, information processing and regulatory function that is an emergent, self-organizing, embodied and relational process of the extended definition of mind.” (p. 507).

The suggestion that intervention, treatment and relational support, can return a brain state to equilibrium in the manner suggested by Siegel (2020), has also been reinforced in research that has plotted the psychological trajectory in students from Pakistan, that leads to suicidal ideation and suicide in late adolescents to early adulthood. According to Khan et al. (2020) suicidal ideation followed by suicide often occurs after long periods of clinical depression and anxiety. Moreover, these states of high levels of distress are frequently associated with early presentations of clinical anger. The authors suggested the key to facilitating effective intervention with these adolescents to prevent suicide and restore normal psychological function, is early assessment, wherever possible at the first signs of “anger or emotional distress…*and*… “vigilant monitoring of anger and emotional distress” (p. 307) by key supportive mentors in their lives, namely parents and teachers. While this study focuses on the psychology of behaviour, the maintenance of active monitoring and supportive relationships has been seen to reduce the incidents of suicide, provided intervention is early.

Mitchell (2009) has approached some of the complexities these questions raise, by suggesting it is not entirely clear that a comprehensive theory of systems can avoid "the integration of concepts from…the domains of… dynamics, information, computation and evolution" (p. 301); however, the author remains firm in a commitment to develop an explanatory model of complexity that fits within systems theory, at the same time mastering the nuances of difference between disciplines. While the author identifies an absence of neuroscience perspectives in the article, they note that future interdisciplinary research could and is transcending current scientific principles of evolution, computational mathematics and biology. Moreover, in a cogent reminder of the broad definitions of complexity and its relevance to the discussions here, Mitchell (2009) posits the hypothesis "that complexity arises and operates by very different processes in different systems" (p. 303). This reflects her depth of understanding of the history, her flexibility and enthusiasm for the kinds of advances we now see in neuroscience, and other interdisciplinary perspectives. At this juncture it is practical to address the brain as a complex system and how challenging behaviour fits into ideas of complexity.

The brain has been described by various neuroscientists as a complex system. That is, complex in structure, dynamic in function and identified essentially by "its social nature" (Johnson and de Haan 2015, p. 122; Maliske and Kanske 2022; Perry 2002; Siegel 2020). Indeed Maliske and Kanske (2022) suggest this dynamism is directly related to the "social brain *that is* interconnected" (p. 1) and able to process copious amounts of information. Of course, there are many perspectives on the social brain, not the least of which has arisen from the interdisciplinary emphasis in neuroscience. For example, Cacioppo et al. (2013) refer to the social brain as intricately orchestrated not just by brain structure and function on its own, but by "gene regulation… *and* neuroendocrine responses…*For example, the discovery of differences in the* serotonin transporter gene" (p. 2) that orchestrates individual children's responses to bullying. Furthermore, they identify the social brain as quintessentially human and not to be segregated from an interdisciplinary understanding. Recent neuropsychiatric perspectives have expanded this idea of multiple interacting systems that reflect the human brain, bringing greater focus on relationships as fundamental to all other functional complexities. (Perry and Winfrey 2021) There are, however, notable exceptions to these views as identified by Elsabbagh and Johnson (2016), when refuting abnormality of brain development relating to the social brain in autism spectrum disorders (ASD).

Siegel (2020) refers to the interconnectedness of the social brain under ideal environmental and relationship conditions as "the connectome" (p. 503). This connectome provides a synchronistic link between multiple systems within and outside the body, interacting with the brain systems in an interconnected and integrated way. In environmental and relationship conditions that are ideal, an individual's brain activates neural responses that work from states of simplicity to increasing complexity in response to internal or external information (Siegel 2020).

In ideal conditions, the sequential nature of brain function in children means that this complex, rapid, and highly integrated neural activity, moderates emotional responses to surrounding environmental conditions and manifests in "self-organization…. in an effort to maximize complexity" (Siegel 2020, p. 98) and to stabilise the integrity of mind and brain. Siegel (2020) suggests that neural activity functions at a rapid "forty-cycle-per second, *that is*, 40-Hz….*in a sweeping pattern of energy…* from front to back in both halves of the brain" (p. 244). In effect, there is a constant cooperative exchange between both hemispheres of the brain under ideal neural conditions; however, wherever integration is constrained by events or memory that is very stressful or traumatic, this smooth transition between the two hemispheres is impeded.

A key component of the social brain is the capacity to process positive, negative, and neutral information about physical appearance, personal behaviour, and others' behaviour, to achieve affective prediction of appropriate self-regulation in order to satisfy a need. There is also a suggestion that it is the "mind…*that is*.…personal subjective experience…*with*…self-awareness and information processing" (Siegel 2020, p. 507) that dictates the electrical activity of the brain, to make sense of the profound interaction of individual engagement in relationship with others; although, Badcock et al. (2019) takes a more deterministic position, identifying brain activity as having strictly "biological…mechanistic" (p. 1320) properties.

There is consensus that when the brain is at the height of efficiency, self-awareness underpins self-regulation and problem solving in the higher cortical areas of the brain, identified as executive functions (Cristaldi et al. 2021); Zelazo (2015) emphasizes the importance of executive function for optimal self-regulation and learning. Furthermore, any inflexibility of brain function because of consistent exposure to stress ultimately inhibits the skills required to problem-solve and self-regulate.

Inefficiency in the neural activity in a child as a result of experiences of adverse events, for example, chronic poverty or trauma, results in non-linear events that inherently set in place, states of interaction between mind and brain that are unpredictable and chaotic (Siegel 2020; Tranquillo 2019). This makes intervention to ameliorate chronic states of anxiety or trauma a difficult and challenging ideal that is possibly incongruent with current methods of behaviour management. This is especially so when it is understood that reactive behaviour in individuals is not always conscious or self-aware. (Delahooke 2019; Porges 2011; Siegel 2020; Sullivan et al. 2014). If, as suggested by neuroscientists, reactions to stress are often mediated by "unconscious emotions" (Perry and Winfrey 2021; Siegel 2020) and consciousness is an integral part of Executive Function (EF) in the brain, then the aim of any intervention must be underpinned by a theoretical construct that takes mind and brain into consideration as the major milestone for positive and effective change in behaviour.

Delahooke (2019) describes challenging behaviour in a way that immediately informs us of non-conscious or unconscious reactiveness to conditions of stress. She suggests that "serious and persistently challenging behaviours are responses to a child's subconscious perception of risk in the physical or relational environment" (Delahooke 2019, p. 20). Moreover, individual responses to apparent and not necessarily realistic threats characteristically result in the reactive, challenging behaviours, that some neuroscientists identify as "non-conscious gut reactions" (Siegel 2020, p. 247) or "faulty neuroception" (Porges 2011, p. 158). These terms describe brain/body determinations of risk in environmental conditions and relationship interactions that are not always accompanied by self-awareness. (Delahooke 2019; Kolacz et al. 2019; Siegel 2020). Chronic reactiveness can result in what Perry and Winfrey (2021) describe as a "dysregulated state dependence" (p. 146) of the brain.

There are also suggestions by neurocognitive scientists that variations in individuals' genetic structure, cultural background, personality traits and socio-economic constraints create variations in impact on how they might manage stressful events (Demir-Lira et al. 2021; Johnson and de Haan 2015; Taylor and Barrett 2019; Van Pelt et al. 2020). Developing neuro-informed approaches to understanding the complexity of individual children with challenging behaviour requires a new paradigm that not only explains non-linearity of chaotic brain states but addresses the diversity that exists in emotional responses from individual to individual, the mercurial nature of emotional processing as it may be dictated by these idiosyncratic features.

Complexity theory as an exploratory paradigm

CT is viewed in Psychology as "a field that studies non-linear systems with very large numbers of interacting variables … such systems are too complex to be accurately predicted but are nevertheless organized and non-random" (APA Dictionary 2007). This reflects one of many definitions from across different scientific disciplines. From a multidisciplinary perspective, CT represents a "descriptive theory" (Mason 2008, p. 6) describing the in-moment reality of random and non-linear fluctuations that impact on the dynamic of complex interacting/interconnected systems. Furthermore, these "symmetry breaking conditions" (Byrne 1998, p. 66) in complex systems can potentially alter that system in permanent and unpredictable ways.

Complexity, representative of changes in complex systems, can either stabilise through an emergent new system, reflected in variables arising within variables, or systems can revert to a chaotic and unpredictable state of complexity. Increasingly, theorists describe complex systems as steeped in the complexity of time and space immediacy (Byrne 1998). If we were to apply CT in an exploratory capacity, developing interventions to facilitate emotional and behavioural self-regulation in children with challenging behaviour, by necessity, we would be required to look closely at the complexity of mind/brain states in these children. The notion of complexity within systems goes some way to explain why some variables are expressed in a non-linear way. That is, those incremental fluctuations in states of mind that can precipitate huge and often chaotic changes are considered non-linear and can temporarily or permanently alter the current state of the system (Byrne 1998; Maliske and Kanske 2022; SanteFe Institute 2022; Siegel 2020). These alterations in states of mind can be conscious or non-conscious (ADHD Australia 2019; Siegel 2020; Trautmann et al. 2022).

Siegel (2020) cites an example of a child who has been exposed to a traumatic event and reacts aggressively to a teacher wearing a particular kind of aftershave. He explains that the immediate emotional response of the child is "somatic *and may or* *may not be* a conscious response" (Siegel 2020, p. 242). The term somatic refers to the transporting of information from the senses to the central nervous system creating "somatic maps" (p. 256) of the physical changes that occur in the body as a result of an individual's experiences. These maps form the blueprint for recognition of the trigger for the brain's future management of similar experiences (Siegel 2020). In the case of the child's response to the aftershave, the trigger is the scent of the aftershave. The sensory response results in the complex engagement of neural activities across brain communities that retrieve memory associated with strong sensory overload experienced at the time of the traumatic event (Porges 2011). Normal neural responses to stressful events result in heightened physiological changes in the body, leading either to reflection and self-regulation or when responding to trauma, to act out in a variety of ways ranging from fight to retreat or disassociation (Kolacz et al. 2019; Perry and Winfrey 2021).

When testing a child's moment-to-moment experience that results in challenging behaviour, the relevance of that individual's state of mind highlights how intricately the brain (as a complex system) is influenced by contexts and varying levels of communication in relationships and diverse environments. This means the inability to make specific scientific predictions of what impact influences emotions at what specific points in time requires some exploration of the diversity that exists in some childhood responses to traumatic experiences. For example, the diverse differences between different individuals in the same family exposed to Domestic violence in their experience of "intrusions of memory, hypervigilance and excessive arousal" (Siegel 2020, p. 105). Perhaps Boroujeni et al. (2019) came close to exposing such differences in their non-linear exploration of EEG signal analysis distinguishing the brain activity of the ADHD child from the brain activity of the relatively stable child.

An exploratory approach to research involves collecting data that is grounded in personal and experiential perspectives on a particular problem. Furthermore, if using a mixed method approach where an exploratory perspective informs and influences a quantitative measurement of the observable problem, Creswell and Creswell (2018) suggest that this is an ideal way of limiting potential deficiencies in research, wherever the truth about human interaction may be diminished by strictly mechanistic means of measurement.

The evidence that non-linear events are unpredictable presents a dilemma for measuring predictability and generalizability using traditional methods of scientific inquiry. While there is increasing use of sophisticated technology to overcome some of these issues of measurement, this is not without its problems; for example, Chen et al. (2022) found strong influences on brain communities from the use of fMRI technology itself. Despite developing a new computational formula to minimise this influence, they conceded limitations on research validity in terms of (a) assessing individual idiosyncratic brain changes and (b) use of some traditional statistical analysis formulas, especially those allowing for generalizability of the research.

Complexity vis a vis generalizability also raises questions about (a) what data to collect that represents the moment-to-moment complexity and (b) whether that data can only describe alterations in the systems rather than the impact of the dependent variable within other independent -apparently insignificant -variables at discreet points in time. Byrne (1998) solution to this dilemma is to use "The Social Survey" (p. 77). He argues the social survey "allow/s us to deal with messy, complex, symmetry breaking, contingent reality as it is" (p. 66). It can be utilized in longitudinal cohort studies to predict the impact of exposure to those key elements. Furthermore, the social survey invokes exploratory reflection and review based on the relationships that exist between the expressions of change and the events that have initiated change. He suggests the CT framework should form the basis of a new model that explores and explains those discreet, sometimes catastrophic variables that may not be considered significant in current models of scientific inquiry. Furthermore, CT is a framework that can be relevant to describing complexity in many disciplinary contexts; however, it cannot necessarily perform as anything but an overarching model for understanding how complex systems function.

So, what does this mean for an exploration of the complex nature of a child's brain, mind and conscious self-awareness using CT as a foundational paradigm of inquiry? There is consensus amongst neuroscientists that the brain is inherently social and functions as a complex system. Furthermore, the "social brain is an inherently dynamic organ" (Maliske and Kanske 2022, p. 4) subject to a similar milieu of complexities-albeit far more convoluted and not yet fully explained-as in other complex systems. Viewing the brain as a complex system functioning in various states of complexity challenges what we should be examining to understand alterations in neural networks influencing the mind under states of duress. It also questions whether the non-linearity of stressful or traumatic events can be measured at all in traditional methods of inquiry. Until we fully understand brain function and the developing mind, a new paradigm may not be feasible and CT may remain an overarching explanation only for the range of complexities that are part of the mind, body and brain systems.

It appears there is consensus that interdisciplinary knowledge is necessary to understand how brain function and other complex systems interact. For example, Neurobiologists focusing on hormonal impairments in individuals attempt to make connections between the brain function underpinning hormonal responses to trauma and The Anterior Cingulate Cortex (hereafter, ACC) (Shirtcliff et al. 2009). The ACC is believed to be associated with the "emotional limbic system and the cognitive pre-frontal cortex" (Stevens et al. 2011, p. 122) with a unique role to manage threatening emotions and self-regulation. Through the use of neuroimaging and clinical observation, it has been noted that psychopathological conditions, known to be manifest in diverse forms of mental health problems, are said to influence whether the ACC is overactive or underactive. This varies substantially between different mental health presentations and has recently been found to depend greatly on the "allostatic load" (Siegel 2020, p. 372) of an individual. That is, the cumulative status of stresses that individual experiences at a particular point in time.

Neuropsychologists are also trained to understand the interrelationships between the brain and neural function, emotion, cognition, and behaviour. In saying this, they too focus on a variety of behaviours that are viewed as challenging. This can be anything from memory loss in different forms of dementia, brain disorders impairing cognitive skills and behaviour, and loss of capacity at the higher cortical levels of the brain (Paulsen and Ghal 2022). Neuropsychologists require neuroimaging, psychometric tools, and statistical measures to justify their practice in assessment and recommended treatment (Reynolds et al. 2011). The use of such tools suggests that quantitative data can justify predictability and generalizability as feasible explanations for abnormal brain presentation and behaviour. However, the discipline of neuropsychology is by no means the only source of understanding of the brain and the mind of those with challenging behaviour despite the benchmarks of respected scientific acceptability (Paulsen and Gehl 2022).

On the other hand, there are neurocognitive scientists who suggest that rates of pre-frontal cortex development, for example, in adolescents whose behaviour can be erratic, risk-taking and impulsive, do not necessarily reflect abnormal mental health conditions. Moreover, the line between functional and dysfunctional neural activity, to a great extent, is inconclusive and still open to new paradigms of research (Johnson and de Haan 2015). Recalling Perry and Winfrey (2021) when discussing the impact of trauma on the brains of individuals, there is agreement that brain development commences from the bottom up in children and is variable in adolescence. Furthermore, neuroimaging has identified that each of our brain unique (Siegel 2020). This raises the spectre of whether current technology has the capacity to accurately reflect what is essentially unstable or even dynamic brain activity without unduly stretching the limits of sophistication of that technology, as Chen et al. (2022) would appear to have discovered.

Despite this information that each brain is unique, there is enough evidence to suggest that the firing of individual and interconnected neural networks follow an ordered organisational process that can be understood through measurements that adhere to quantitative dictums of science. In effect, in experimental settings, technology has revealed that through memory, the brain prepares itself for a future reoccurrence of an event and responds to similar or identical stimuli with this preparation in mind. This suggests there is a pattern of probability in the neural mechanics of the way the brain may react to aversive experiences. It may also mean the presence of complexity is not always non-linear (Siegel 2020).

Byrne (1998) reinforces this by suggesting in the social sciences, despite the limitations of quantitative methods, statistical models of scientific inquiry have indeed been developed to explain the complexity in multiple systems in modernity. As such, they can be understood to be a "real effort to understand our world" (p. 87) and are therefore, amenable to change, using CT principles to explore new ways of describing the uncertainty in non-linear presentations within those systems. So, given that neuroimaging provides information about brain function in a mechanistic way, despite an attempt to identify specific patterns of pathological brain function, it is not conclusive that the minutiae of reactiveness in children presenting with challenging behaviour, can be effectively measured to current satisfactory scientific protocols. It follows that there is difficulty in the use of CT as a theoretical framework for describing the in-the-moment reality of adverse experiences because of the diversity in children's neural responses to these experiences. This makes research viability a very precarious exercise.

This may leave CT in the limbo described by Byrne (1998) between traditional linear science, linearity in complex systems and non-linear complexity leading to chaos. Perhaps as Mason (2008) suggests, CT must remain a descriptive theory at the earliest stages of descriptive analysis, without the statistical formulas to provide an in-depth quantitative analysis of what we are seeking to understand in the mind/brain activity of individuals/adolescents with challenging behaviour. It means, of course, that his idea of the social survey has strong relevance in a qualitative sense for collecting data firsthand in a local and temporal context. It could also factor in a causal connection with the data which then questions how this would relate to the immediacy of the experience.

When exploring the complexity of the brain, the emergence of more sophisticated technology, for example, Functional Magnetic Resonant imaging (fMRI) and advanced electroencephalogram, may have answers to what is happening organically; however, without being able to reach a consensus about what is the crucial starting point for emotional reactiveness and cognitive dissonance, leading to behavioural problems in children and adolescents (Dugr´e et al. 2020). Moreover, CT is unable to fulfill quantitative data expectations of complexity implicit in non-linear mind/brain interactions. In saying this, CT may be viewed as an effective means of exploring the qualitative parameters of the mind/brain complexity. Despite the criticisms that qualitative research is the poor cousin of quantitative research, perhaps the human mind and conscious awareness dictate against prescriptive benchmarks of scientific scrutiny as they currently exist (Creswell and Creswell 2018). Indeed, Byrne (1998) would argue that CT has the potential for exposing that non-linearity as a prescription for realism inquiry, is more ably suited to understand the interconnectedness of the mind with the brain, however not necessarily in a way that can be measured using current scientific methods, even those methods that are exploring brain function through the use of technology.

Of course, the intersections of similarity that each discipline demonstrates in seeking to describe complexity have the advantage of forming bridges of explanation that could provide the foundation for a more refined CT approach to measuring non-linearity. For example, Siegel (2020) not only makes connections of compatibility between, for example, neurological and biological information processing, but has developed as a result of observing the interdisciplinary approaches to complexity, what he terms "The 3 P framework" (p. 5). This framework intersects the body in the natural world, with the self in relationships with others, with the mind "as an embodied and relational process that regulates the flow of energy and information… *identifying this as* the triangle of human experience" (p. 5). This embodies "physical sensations, perceptions, ideas, concepts and words" (p. 14) and embraces the notion that human agency is at the heart of any understanding of complexity. Social factors, motivations, beliefs, and experiences make this world complex and our understanding of complexity is driven by deeper questions than can be asked in current models of scientific inquiry. Questions that explore why things happen, what matters most, what matters more, how important context is, and how parts of the puzzle of complexity interact (Byrne 1998; Cacioppo et al. 2013; Johnson 2009; Siegel 2020).

Conclusion

Complexity theory is an evolving theory to explain and potentially explore the nuances of complexities in existing and future complex systems. CT, as discussed here, primarily underpins a sociological interpretation of complex social systems;

however, it has evolved from mathematical explanations of chaos. As such, it has been identified as crucial to describing complex systems from multidisciplinary perspectives and an efficient framework for exploring and reviewing non-linearity in these systems. This is not to say that CT is only applied in a sociological context. It is, indeed, a framework that has been used to explain brain structure and function as a complex system. In exploratory terms, CT has the potential for unravelling the complexity behind challenging behaviour in children: however, one which is generally descriptive. Nevertheless, as a composite of historical theories about chaos, CT efficiently exposes the non-linearity in random events. At the same time it has the capacity to reveal the adaptability of complex systems. In its current form, as an exploratory means of understanding the minutiae of states of mind and levels of consciousness that reflect individuals' responses to adverse conditions, it may lend itself to an adaptation within, for example, Siegel (2020) 3 P framework.

Nor does it refute the gap between the efficacy of CT and current methods of scientific inquiry in the development of hypotheses about challenging behaviour. There is no dispute here: however, this gap in the application of CT to an understanding of challenging behaviour in children is partly due to the interdisciplinary nature of neurological explanations of brain and behaviour. Similarly, the separation of complex systems from the dynamic of human agency. Of course, this inconclusive and uncertain element identified in current thinking and future research also dovetails neatly with CT underwriting the dynamic states of brain structure and function. Furthermore, the increasing use of computational formulas and powerful diagnostic systems; for example, EEG and fMRI, demonstrates the fragility of mechanistic systems of inquiry under the mantle of increasingly exposed non-linearity in brain function. Finally, in its current form, CT provides the basis to explore non-linearity in systems that are complex, not the least of which is the brain. It has the potential, alongside other theoretical frameworks and advanced technology, to underpin new paradigms for scientific inquiry that effectively inform the non-linearity of diversity in mind and brain contributing to challenging behaviour in children.

Acknowledgements This paper is extracted from my PhD thesis at the University of Newcastle Australia. I wish to express my gratitude to Dr Judith Foggett, Dr Angela Page and Dr. Sharon Savage for their insightful comments and suggestions during my PhD journey.

Author contributions The manuscript was written by the author and the author read and approved the final manuscript. No other authors are involved in the writing process.

Funding Open Access funding enabled and organized by CAUL and its Member Institutions. No funds, grants, or other support were received.

Data availability Data availability is not applicable for this manuscript.

Declarations

Conflict of interest The author has no conflicting interests to declare that are relevant to the content of this article.

Ethical approval This article does not contain any studies with human participants performed by any of the authors.

References

ADHD Australia (2019) The role of executive functions. https://www.adhdaustralia.org.au/about-adhd/the-role-of-executive-functioning-in-adhd/

Anand KS, Dhikav V (2012) Hippocampus in health and disease: an overview. Ann Indian Acad Neurol 15(4):239–246, ISSN 0972-2327 URL https://journals.lww.com/annalsofian/Fulltext/2012/15040/Hippocampus_in_health_and_disease__An_overview.2.aspx

Anderson OR (2009) Neurocognitive theory and constructivism in science education: a review of neurobiological cognitive and cultural perspectives. Brunei Int J Sci Math Edu 1(1):1–32, ISSN 2076-0868

APA Dictionary (2007) APA dictionary of psychology. American Psychological Association, Washington. ISBN 1-59147-380-2; 978-1-59147-380-0

Baars B, Gage N (2010) Cognition, brain, and consciousness. 2nd edn. Elsevier Science and Technology, ISBN 0123750709; 9780123750709

Badcock PB, Friston KJ, Ramstead MJD, Ploeger A, Hohwy J (2019) The hierarchically mechanistic mind: an evolutionary systems theory of the human brain, cognition, and behavior. Cogn Affect Behav Neurosci 19(6):1319–1351. https://doi.org/10.3758/s13415-019-00721-3

Barbot B, Safont-Mottay C, Oubrayrie-Roussel N (2019) Multidimensional scale of self-esteem (EMES-16): Psychometric evaluation of a domain-specific measure of self-esteem for French-speaking adolescents. Int J Behav Dev 43(5):436–446. https://doi.org/10.1177/0165025418824996

Boroujeni YK, Rastegari AA, Khodadadi H (2019) Diagnosis of attention deficit hyperactivity disorder using non-linear analysis of the EEG signal. IET Syst Biol 13(5):260–266. https://doi.org/10.1049/iet-syb.2018.5130

Buckner RL, DiNicola LM (2019) The brain's default network: updated anatomy, physiology and evolving insights. Nat Rev Neurosci 20(10):593–608. https://doi.org/10.1038/s41583-019-0212-7

Byrne D (1998) Complexity theory and the social sciences : an introduction. Taylor & Francis Group, Milton Park ISBN 9780203003916

Cabanac M (2002) What is emotion? Behav Proc 60:69–84. https://doi.org/10.1016/S0376-6357(02)00078-5

Cacioppo JT, Cacioppo S, Cole SW (2013) Social neuroscience and social genomics: the emergence of multi-level integrative analyses. Int J Psychol Res 6:1–6. https://doi.org/10.2150/20112084.711

Casadevall A, Fang FC (2009) Mechanistic science. Infect Immun 77(9):3517–3519. https://doi.org/10.1128/IAI.00623-09

Chen AA, Srinivasan D, Pomponio R, Fan Y, Nasrallah IM, Resnick SM, Beason-Held LL, Davatzikos C, Satterthwaite TD, Bassett DS, Shinohara RT, Shou H (2022) Harmonizing functional connectivity reduces scanner effects in community detection. NeuroImage (Orlando, Fla) 256:119198–119198. https://doi.org/10.1016/j.neuroimage.2022.119198

Creswell JW, Creswell JD (2018) Research design: qualitative, quantitative & mixed methods approaches, 5th edn. SAGE, Thousand Oaks ISBN 9781506386621

Cristaldi FD, Mento G, Buodo G, Sarlo M (2021) What's next? Neural correlates of emotional predictions: a high-density eeg investigation. Brain Cogn 150:1057. https://doi.org/10.1016/j.bandc.2021.105708

Delahooke M (2019) Beyond behaviors: using brain science and compassion to understand and solve children's behavioral challenges. Pesi Publishing and Media Pesi Inc. ISBN 9781683731191

Demir-Lira ÖE, Prado J, Booth JR (2021) Neurocognitive basis of deductive reasoning in children varies with parental education. Hum Brain Mapp 42(11):3396–3410. https://doi.org/10.1002/hbm.25441

Dugré JR, Radua J, Carignan-Allard M, Dumais A, Rubia K, Potvin S (2020) Review article neurofunctional abnormalities in antisocial spectrum: a meta-analysis of fMRI studies on Five distinct neurocognitive research domains. Neurosci Biobehav Rev 119:168–183. https://doi.org/10.1016/j.neubiorev.2020.09.013

Elsabbagh M, Johnson MH (2016) Autism and the social brain: the first-year puzzle. Biol Psychiat 80(2):94–99. https://doi.org/10.1016/j.biopsych.2016.02.019

Everaerta J, Bronsteinb MV, Castrob AA, Tyrone D, Cannonb TD, Joormannb J (2020) When negative interpretations persist, positive emotions don't! Inflexible negative interpretations encourage depression and social anxiety dampening positive emotions. Behav Res Ther. https://doi.org/10.1016/j.brat.2019.103510

Giedd JN (2004) Structural magnetic resonance imaging of the adolescent brain. Ann New York Acad Sci. https://doi.org/10.1196/annals.1308.009

Haas SM, Becker SP, Epstein JN, Frick PJ (2018) Callous-unemotional traits are uniquely associated with poorer peer functioning in school-aged children. J Abnorm Child Psychol 46(4):781–793. https://doi.org/10.1007/s10802-017-0330-5

Headway, The Brain Association (2023) What are executive functions. https://www.headway.org.uk/. Accessed 22 June 2021. https://www.headway.org.uk/about-brain-injury/individuals/effects-of-brain-injury/executive-dysfunction/#whichPart

Hormazabal F, Lavanderos L, Malpartida A (2021) Biocybernetic model for the diagnosis and treatment of chronic pain: An approximation from cognitive neurosciences and the theory of complexity. Kybernetes 50(2):369–385. https://doi.org/10.1108/K-07-2019-0469

Isquith PK, Gioia GA, Guy SC, Kenworthy L (2015) Brief 2 behaviour rating inventory of executive function: teacher forminterpretive report-sample. 2nd Ed., U.S.A

James W (2020) What is an emotion? Mind 9(34):188–205. https://www.jstor.org/stable/2246769

Johnson MH, de Haan M (2015) Developmental cognitive neuroscience : An introduction. Wiley, Hoboken. ISB 9781118938102

Johnson N (2009) Simply complexity: A clear guide to complexity theory Nature 461(7268):1207. ISSN 0028–0836

Khan S, Mubashar T, Akhtar T, Butt TA (2020) Impact of anger on suicidal ideation: mediating role of perceived emotional distress in late adolescents and emerging adults with psychological problems. Pak J Psychol Res 35(2):295–312. https://doi.org/10.3382/PJPR.2020.35.2.16

Kolacz J, Kovacic KK, Porges SW (2019) Traumatic stress and the autonomic brain-gut connection in development: Polyvagal Theory as an integrative framework for psychosocial and gastrointestinal pathology. Dev Psychobiol 61(5):796–809. https://doi.org/10.1002/dev.21852

Ladyman J, Wiesner K (2020) What Is a Complex System? Yale University Press. https://doi.org/10.2307/j.ctv14rmpwc

Maliske L, Kanske P (2022) The social connectome - moving toward complexity in the study of brain networks and their interactions in social cognitive and affective neuroscience. Front Psych 13:845492–845492. https://doi.org/10.3389/fpsyt.2022.845492

Mason M (2008) Complexity theory and the philosophy of education. Educ Philos Theory 40(1):4–18. https://doi.org/10.1111/j.1469-5812.2007.00412

Mitchell M (2009) Complexity: a guided tour. Oxford University Press, Oxford. ISBN 978-0-19-512441-5

National Scientific Council on the developing child (2020) Connecting the Brain to the rest of the body: early childhood development and lifelong health are deeply intertwined. Harvard University. Accessed 25 Aug. https://developingchild.harvard.edu/resources/connecting-the-brain-to-the-rest-of-the-body-early-childhood-development-and-lifelong-health-are-deeply-intertwined/

Ochsner KN, Gross JJ (2008) Cognitive emotion regulation: insights from social cognitive and affective neuroscience. Curr Directions Psychol Sci J Am Psychol Soc 17(2):153–158. https://doi.org/10.1111/j.1467-8721.2008.00566.x

Paulsen JS, Gehl C (2022) Goals of neuropsychology. In: Jankovic J (ed) bradley and daroff's neurology in clinical practice. 44:614–632.e5. ISBN 0-323-64261-6

Perry BD (2002) Childhood experience and the expression of genetic potential: what childhood neglect tells us about nature and nurture. Brain Mind 3:79–100. ISBN 1389-1987

Perry BD, Winfrey O (2021) What happened to you?: Conversations on trauma, resilience, and healing. Pan MacMillan, London. ISBN 9781529068474
Perry BD (2020) The neurosequential model: A developmentally sensitive, neuroscience informed approach to clinical problem-solving. https://www.neurosequential.com/nme
Porges SW (2011) The polyvagal theory: Neurophysiological foundations of emotions, attachment, communication, and self-regulation, 1st edn. Norton & Co, New York, ISBN 978-0-393-70700-7
Reynolds CR, Kamphaus RW, Vannest KJ (2011) Behavior assessment system for children (BASC). In: Kreutzer JS, DeLuca J, Caplan B (eds) Encyclopedia of clinical neuropsychology. Springer, New York, pp 366–371. https://doi.org/10.1007/978-0-387-79948-3_1524
Rickles D, Hawe P, Shiell A (2007) A simple guide to chaos and complexity. J Epidemiol Community Health 61(11):933–937. https://doi.org/10.1136/jech.2006.054254
Rudlin K (2022) What is dysfunctional behavior in families?. https://www.verywellmind.com/dysfunctional-defined-2610364
Sanna F, Serra MP, Boi M, Bratzu J, Poddighe L, Sanna F, Carta A, Corda MG, Giorgi O, Melis MR, Argiolas A, Quartu M (2022) Neuroplastic changes in c-Fos, ΔFosB, BDNF, trkB, and Arc expression in the hippocampus of male Roman rats: differential effects of sexual activity. Hippocampus 32(7):529–551. https://doi.org/10.1002/hipo.23448
SanteFe Institute (2022) Applied complexity. Santa Fe Institute. Accessed July 2022. https://www.santafe.edu/applied-complexity/office
Schafer M, Schiller D (2018) Navigating social space. Neuron Cambridge Mass 100(2):476–489. https://doi.org/10.1016/j.neuron.2018.10.006
Shirtcliff EA, Vitacco MJ, Graf AA, Gostisha AJ, Merz JL, Zahn-Waxler C (2009) Neurobiology of empathy and callousness implications for the development of antisocial behavior. Behav Sci Law 27(2):137–171. https://doi.org/10.1002/bsl.862
Siegel DJ (2020) The developing mind: How relationships and the brain interact to shape who we are, 3rd edn. The Guilford Press, New York. ISBN 9781462542758
Siegel DJ, Drulis C (2023) An interpersonal neurobiology perspective on the mind and mental health: personal, public, and planetary well-being. Ann Gen Psychiatry 22(1):5–5. https://doi.org/10.1186/s12991-023-00434-5
Sporns O (2013) Structure and function of complex brain networks. Dialogues Clin Neurosci 15(3):247–262. https://doi.org/10.3188/DCNS.2013.15.3/osporns
Stevens FL, Hurley RA, Taber KH, Hayman LA (2011) Anterior cingulate cortex: uniqure role in cognition and emotion. J Neuropsychiatr Clin Neurosci. https://doi.org/10.1176/jnp.23.2.jnp121
Sullivan AM, Johnson B, Owens L, Conway R (2014) Punish them or engage them? Teachers' views of unproductive student behaviours in the classroom. Aust J Teacher Educ. https://doi.org/10.14221/ajte.2014v39n6.6
Taylor L, Barrett W (2019) Developing a trauma-informed approach to closing the poverty-related attainment gap. Educ Child Psychol 35(3):64–75. https://doi.org/10.53841/bpsecp.2018.35.3.64
Tranquillo J (2019) An introduction to complex systems: Making sense of a changing world, 1st edn. Springer International Publishing, New York. ISBN 3030025896–9783030025892
Trautmann S, Wittgens C, Muehlhan M, Kanske P (2022) The role of socio-affective and socio-cognitive mechanisms in the processing of witnessed traumatic events. Front Psychiatr. https://doi.org/10.3389/fpsyt.2022.830218
van der Aar LPE, Crone EA, Peters S (2019) What characterizes adolescents struggling with educational decision-making?: The role of behavioral and neural correlates of self-concept and self-esteem. Mind Brain Educ. https://doi.org/10.1111/mbe.12209
Van Pelt AE, Lipow MI, Scott JC, Lowenthal ED (2020) Interventions for children with neurocognitive impairments in resource-limited settings: a systematic review. Child Youth Serv Rev 118:105393. https://doi.org/10.1016/j.childyouth.2020.105393
Wang YN, Zhang L, Kong XZ, Hong YY, Cheon B, Liu J (2016) Pathway to neural resilience: Self-esteem buffers against deleterious effects of poverty on the hippocampus. Hum Brain Mapp 37(11):3757–3766. https://doi.org/10.1002/hbm.23273
Zelazo PD (2015) Executive function: Reflection, iterative reprocessing, complexity, and the developing brain. Dev Rev 38:55–68. https://doi.org/10.1016/j.dr.2015.07.001

Authors and Affiliations

Krista Tomas[1]

✉ Krista Tomas
Krista.tomas@uon.edu.au

1 The School of Education, The University of Newcastle, Callaghan, NSW, Australia