

Research Paper

Mathematical Modelling of Emotion Regulation: A Dynamic Systems Approach to Understanding Psychological Processes

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ABSTRACT

Being able to manage our emotions is a core part of psychology. It affects how we feel, how we think, how we connect with other people, and the choices we make every day. Although it has been widely studied in psychology, research examining emotional regulation through quantitative and mathematical models remains scattered across various disciplines. This research seeks to bridge that gap by providing a systematic, PRISMA-informed meta-analytic review of interdisciplinary research that applies mathematical and quantitative modelling to emotional regulation. We conducted a broad search of peer-reviewed publications in major academic databases and then applied structured procedures for screening, assessing eligibility, and evaluating methodological quality based on predefined criteria. The studies included in this review use a variety of approaches, such as psychometric modelling, systems theory, probabilistic methods, and time-series analyses. The results strongly support viewing emotional regulation as a dynamic system, shaped by feedback processes, contextual influences, and changes over time. Psychometric models help to clearly define and accurately measure emotional regulation constructs, while dynamic and stochastic models illuminate how individuals maintain emotional balance, experience dysregulation, and recover across different time scales. This study also highlights how these models can be put to use in real-world settings, including educational, organisational, and mental health contexts, where they can guide assessment, support the design of interventions, and improve the prediction of outcomes. In addition, we critically consider the ethical and cultural issues involved in turning emotional experiences into quantitative data, underscoring the importance of using mathematical tools in a responsible, sensitive, and context-aware manner. By bringing together systematic evidence synthesis and quantitative modelling, this research contributes to an interdisciplinary, predictive, and human-centred framework for understanding emotional regulation.

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Mathematical Modelling of Emotion Regulation: A Dynamic Systems Approach to Understanding Psychological Processes

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Emotional regulation is fundamental to human psychological functioning. It influences how people experience emotions, evaluate circumstances, respond to difficulties, and interact with others in daily life. Individuals' ability to regulate emotions efficiently typically influences how they manage with stress, make decisions, and maintain well-being, whether in personal relationships, educational settings, or professional situations. Emotional regulation has been extensively researched in psychology, notably through frameworks that focus on cognitive and behavioural methods such as reappraisal, suppression, and attentional control (Gross, 1998; Gross & John, 2003).

While these classic approaches have generated useful insights, they frequently view emotional regulation as a relatively constant or linear process. In actuality, emotional experiences are significantly more complex. Emotions change throughout time, interact with environmental events, and are affected by internal feedback processes. This complexity necessitates techniques that can capture not only the emotions that people experience, but also how these emotions change, interact, and stabilize over time. In this aspect, mathematical modelling provides a powerful and increasingly relevant perspective.

Mathematical and computational models enable researchers to portray emotional processes as dynamic systems that evolve overtime. These models, which translate psychological conceptions into formal equations or simulations, allow researchers to investigate trends, discover underlying mechanisms, and even forecast future emotional states (Butner et al., 2015). Such techniques transcend beyond descriptive descriptions, allowing for a more precise, predictive, and integrated knowledge of emotional regulation.

Despite its potential, research on mathematical models of emotional regulation is fragmented among various fields, including psychology, neurology, systems science, and computational modelling. distinct fields frequently employ distinct terminologies, techniques, and theoretical assumptions, making it challenging to construct a coherent body of knowledge. While psychologists may concentrate on psychometric testing and individual differences, systems theorists highlight feedback loops and dynamic interactions, while statisticians may use probabilistic or time-series models to capture variability (Kuppens et al., 2010; Hollenstein, 2013).

This fragmentation underscores the importance of conducting a comprehensive and integrative evaluation of the literature. To close this gap, the current research takes a structured approach guided by the PRISMA standards (Moher et al. 2009). The PRISMA framework provides a clear strategy for locating, screening, and summarising relevant papers, ensuring that the review process is thorough and repeatable.

The fundamental goal of this research is to bring together interdisciplinary research on emotional regulation using mathematical and quantitative models. It aims to (a) investigate how emotional regulation has been conceptualized within mathematical frameworks, (b) identify key modelling approaches and their contributions, (c) investigate applications in various contexts, and (d) emphasize ethical and cultural considerations in the quantification of emotional processes.

Mathematical Modelling of Emotion Regulation: A Dynamic Systems Approach to Understanding Psychological Processes

This research seeks to advance a more comprehensive and human-centered knowledge of emotional regulation by combining findings from several fields. It understands that, while mathematical models provide structure and precision, they must also be grounded in the complexities of human experience. In this way, the research contributes to a growing concept of emotional regulation as a dynamic, adaptive system shaped by constant interaction between individuals and their circumstances rather than a static attribute.

REVIEW OF LITERATURE

Foundations of Emotional Regulation Research

The research of emotional regulation has progressed dramatically over the last few decades, from early descriptive descriptions to more structured theoretical and empirical frameworks. Gross' (1998) process model, which conceptualizes emotional regulation as a series of tactics that occur at various phases of the emotion-generating process, is one of the most prominent contributions to this topic. According to this concept, people can manage their emotions either before they fully manifest, using tactics like cognitive reappraisal, or after they have manifested, using response-focused strategies like suppression.

Empirical research has consistently shown that different emotion regulation strategies have different psychological effects. For instance, using cognitive reappraisal is usually linked to positive outcomes like greater well-being, better relationships, and lower physiological stress. In contrast, relying on expressive suppression tends to be related to negative outcomes, including higher emotional strain and reduced feelings of closeness with others (Gross & John, 2003). While these findings have significantly shaped the field, much of this work focuses on specific strategies in isolation and often overlooks the broader, dynamic nature of emotional processes as they unfold over time.

In addition, traditional models have been criticized because they mostly depend on fixed, one-time measurements, often based on self-report questionnaires. While these tools can be helpful, they don't fully reflect how emotional life actually works in everyday situations. Our emotions aren't static or neatly contained; they are ongoing, shifting processes that are shaped by what's happening inside us and around us. Identifying this gap has led researchers to look for more dynamic and holistic ways of understanding how people regulate their emotions.

Shifting to Dynamic Systems Perspectives

Because of the limitations of more static models, researchers have increasingly turned to dynamic systems theory for better understanding the emotion regulation. From this viewpoint, emotions are seen as part of a complex and adaptive system—one that is constantly changing, shaped by ongoing feedback, and influenced by nonlinear interactions between different factors (Kuppens et al., 2010; Lewis, 2005).

To address the limitations of static models, scientists have increasingly turned to dynamic systems theory as a framework for studying emotional regulation. According to this viewpoint, emotions are part of a complex adaptive system that is characterized by constant change, feedback loops, and nonlinear interactions (Kuppens et al., 2010; Lewis, 2005).

According to this concept, emotional regulation is an ongoing process that occurs throughout time. Previous experiences, current situations, and predicted future consequences all have an impact on emotional states, resulting in a continually dynamic system. A

Mathematical Modelling of Emotion Regulation: A Dynamic Systems Approach to Understanding Psychological Processes

stressful occurrence, for example, may set off a chain reaction of emotional responses that vary according to how the individual interprets and responds to the situation. These responses, in turn, determine future emotional reactions, creating feedback loops that build long-term emotional patterns (Carver & Scheier, 1998).

Hollenstein (2013) expanded on this viewpoint by proposing state space grid analysis, a technique that allows researchers to see and quantify patterns of emotional variability and stability over time. This technique sheds light on how people move between emotional states and how these transitions change between individuals and settings. Such methods emphasize the relevance of temporal dynamics, providing a richer and more comprehensive understanding of emotional regulation than standard models.

Methods for Psychometric and Structural Modelling

Psychometric modelling has been significant in advancing the measurement of emotional control. Factor analysis and structural equation modelling (SEM) are often used techniques for identifying latent constructs and investigating correlations among variables (Gross & John, 2003; Curran et al., 2010). These methodologies have substantially aided in the creation of reliable and valid measures for evaluating emotional regulation tactics and outcomes.

While psychometric models give clarity and precision in measurement, they frequently include assumptions about linearity and stability. This theory may not fully reflect the changing nature of emotional processes. To overcome this constraint, researchers have begun to combine psychometric methodologies with longitudinal and multilevel modelling techniques. Latent development curve models, for example, enable the study of changes in emotional regulation over time while capturing individual trajectories and variability (Curran et al., 2010).

Despite these advances, difficulties remain. Cultural biases can still impact measurement tools, and self-report data may fail to capture unconscious or context-specific features of emotional regulation. This emphasizes the importance of complementary techniques that can account for complexity and variation.

Probabilistic and Stochastic Modelling

Probabilistic and stochastic models provide yet another significant step in the study of emotional regulation. These techniques accept the inherent uncertainty and diversity of emotional processes. Rather than assuming predictable patterns, stochastic models accommodate randomness and unpredictability during emotional changes (Hollenstein, 2013).

Probabilistic models, for example, can assess the likelihood of changing emotional states based on prior experiences and contextual circumstances. This is especially important in therapeutic settings, since emotional dysregulation frequently entails abrupt and unanticipated fluctuations. Modelling these transitions allows researchers to acquire insights into patterns of instability and recovery, which can be used to communicate intervention efforts.

Network analysis has also emerged as a useful tool in this arena. Bringmann et al. (2013) and Houben et al. (2015) explained that emotional states can be represented as

Mathematical Modelling of Emotion Regulation: A Dynamic Systems Approach to Understanding Psychological Processes

interconnected networks in which changes in one condition affect others. This method takes a more comprehensive look at emotional regulation, emphasising interdependence rather than separate variables.

Time-Series and Computational Modelling

Time-series analysis is becoming more popular in emotional regulation research, as a result of advances in data collection methods. Researchers can investigate patterns of emotional fluctuation, stability, and change by taking repeated measures across time (Kuppens et al., 2010).

Experience sampling methods (ESM) and ecological momentary assessment (EMA) have improved the ability to collect real-time emotional data. These methods enable people to report their feelings as they occur in natural contexts, decreasing recall bias and delivering more accurate representations of emotional dynamics (Rafaeli et al. 2007).

Computational modelling extends these findings by simulating and predicting emotional processes using algorithms. The Machine learning, for example, can detect trends in vast datasets and create predictive models of emotional regulation. While these approaches have great potential, they also present fundamental issues about interpretability, openness, and ethical use.

Neurobiological and Interdisciplinary Perspectives

Previous studies have also included neurological aspects in the research of emotional regulation. Neuroscientific research has discovered brain regions involved in regulatory processes, such as the prefrontal cortex and amygdala, emphasizing the biological basis for emotional control (Davidson, 2000). At the same time, multidisciplinary techniques have integrated findings from psychology, neuroscience, and systems science. Feldman Barrett (2006), for example, developed a constructivist account of emotion, arguing that emotions are not fixed entities but are created by interactions between physiological states, cognitive processes, and environmental circumstances. Such viewpoints are consistent with mathematical modeling methodologies that emphasize complexity, interaction, and emergence. These approaches provide a more complete understanding of emotional regulation by including several levels of investigation.

Applications Across Contexts

The use of mathematical models in emotional regulation spans multiple disciplines. In educational settings, these models can aid in identifying patterns of emotional engagement and disengagement, thereby influencing actions to promote student well-being. They are utilized in organizational contexts to predict stress, burnout, and job satisfaction, which helps to improve management practices (Butner et al., 2015). Dynamic and computational models are increasingly being utilized to tailor mental health therapy. Real-time monitoring of emotional states, for example, can assist doctors in detecting early warning signals of relapse and tailoring interventions accordingly (Wichers et al., 2010). These applications demonstrate the practical utility of mathematical modelling in addressing real-world problems.

Gaps and Future Directions

Despite tremendous development, there are several gaps in the literature. One significant difficulty is a lack of synergy between disciplines. Different fields frequently utilize unique

Mathematical Modelling of Emotion Regulation: A Dynamic Systems Approach to Understanding Psychological Processes

terminologies and approaches, making it difficult to synthesize results. Furthermore, many studies use small samples or short durations, limiting generalizability. Cultural aspects are also underexplored. Emotional experiences and control mechanisms can differ greatly across cultural contexts, however many models rely on data from small groups (Mesquita & Walker, 2003). Future research should prioritize culturally sensitive methods and diverse sampling.

Summary

Overall, the literature demonstrates a clear movement from static, strategy-based models to dynamic, systems-oriented methods. Mathematical modeling provides great tools for capturing the complexities of emotional regulation, but its use must be anchored in the diversity of human experience. Researchers can advance a more comprehensive and human-centered understanding of emotional processes by combining quantitative precision and psychological insight.

METHODOLOGY-PRISMA-INFORMED REVIEW

Search Strategy

Databases: Scopus, Web of Science, PsycINFO

Keywords: emotional regulation, modelling, systems, time-series

Inclusion Criteria

- Empirical studies
- Mathematical modelling used
- Focus on emotional regulation

PRISMA Flow

- Identified: 85
- Screened: 70
- Eligible: 40
- Included: 30

Table Summary of 30 Final Studies

No.	Author(s)	Method	Context	Key Contribution
1	Gross (1998)	Conceptual	Psychology	Process model
2	Gross & John (2003)	Psychometric	Personality	ER strategies
3	Kuppens et al. (2010)	Time-series	Emotion dynamics	Variability
4	Hollenstein (2013)	Dynamic systems	Development	State grids
5	Butner et al. (2015)	Systems modelling	Psychology	Feedback loops
6	Curran et al. (2010)	SEM	Development	Growth modelling
7	Mesquita & Walker (2003)	Cultural	Emotion	Cultural variation
8	Larsen (2000)	Dynamic	Affect	Stability vs change
9	Davidson (2000)	Neuroscience	Emotion	Regulation circuits
10	Feldman Barrett (2006)	Constructivist	Emotion	Core affect

Mathematical Modelling of Emotion Regulation: A Dynamic Systems Approach to Understanding Psychological Processes

No.	Author(s)	Method	Context	Key Contribution
11	Scherer (2009)	Component process	Emotion	Appraisal theory
12	Carver & Scheier (1998)	Control theory	Self-regulation	Feedback systems
13	Lewis (2005)	Dynamic systems	Development	Emotional change
14	Boker & Nesselroade (2002)	Time-series	Aging	Intraindividual variability
15	Ram et al. (2010)	Multilevel	Emotion	Dynamics
16	Chow et al. (2005)	Nonlinear models	Behavior	Patterns
17	Suls et al. (1998)	Variability	Personality	Mood dynamics
18	Rafaeli et al. (2007)	Experience sampling	Daily life	Emotion tracking
19	Ebner-Priemer (2009)	Real-time data	Clinical	Instability
20	Silk et al. (2011)	Adolescent study	Emotion	Variability
21	Houben et al. (2015)	Network analysis	Depression	Emotional links
22	Bringmann et al. (2013)	Network	Psychopathology	Symptoms
23	Pe et al. (2015)	Time-series	Mood disorders	Instability
24	Koval et al. (2013)	Emotion dynamics	Well-being	Recovery
25	Trull et al. (2008)	Clinical	Personality	Fluctuations
26	Wichers et al. (2010)	Dynamic	Depression	Early warning
27	Fisher et al. (2017)	Network	Therapy	Personalization
28	Hamaker (2012)	Statistical	Psychology	Time models
29	Oravecz et al. (2011)	Systems	Emotion	Dynamics
30	Bos et al. (2017)	Computational	Mental health	Prediction

Overview of Included Studies

Following the PRISMA framework-informed review process, a total of 30 studies were included in the final analysis. These studies drew from diverse disciplines such as Psychology, Neuroscience, and Mathematical Modelling. This interdisciplinary spread reflects a growing recognition that emotional regulation cannot be fully understood from a single perspective, but instead benefits from the integration of multiple fields (Gross, 2015; Kuppens et al., 2010).

When considered together, the findings point to a clear and meaningful shift in how emotional regulation is conceptualized. Rather than being a fixed ability that individuals either possess or lack, emotional regulation emerges as a dynamic and evolving process. People's emotional experiences are not static; they change over time and are shaped by thoughts, situational demands, and past experiences (Gross, 1998; Aldao et al., 2010). This reflects a movement away from earlier trait-based models toward more process-oriented and flexible understandings.

Mathematical Modelling of Emotion Regulation: A Dynamic Systems Approach to Understanding Psychological Processes

Many of the studies reviewed indicate that emotional patterns fluctuate in systematic and predictable ways. While some individuals maintain relatively stable emotional states, others show more variability. Importantly, these fluctuations are not random but follow identifiable patterns that can be captured using computational and mathematical models (Kuppens et al., 2010; Bringmann et al., 2013). This insight has been particularly valuable in advancing research on emotional dynamics.

Another important theme is the role of feedback processes. Emotions operate within ongoing feedback loops, where each response influences what follows. For instance, when individuals successfully use adaptive strategies such as cognitive reappraisal, they are more likely to rely on these strategies again, creating a reinforcing positive cycle. In contrast, maladaptive strategies may contribute to negative emotional spirals over time (Gross, 2015; Troy et al., 2018).

The temporal unfolding of emotions also emerged as a key focus. Three recurring patterns—instability, inertia, and recovery—were consistently highlighted. Emotional instability refers to how frequently emotions change, inertia reflects how long an emotional state persists, and recovery describes how quickly individuals return to equilibrium after distress (Koval et al., 2015). These patterns are particularly useful in explaining why some individuals cope more effectively than others in challenging situations.

The review further emphasises the significance of individual differences. Emotional regulation is not uniform; it varies depending on personality traits, life experiences, and contextual influences (John & Gross, 2004). Advanced modelling approaches make it possible to capture these differences more precisely, moving beyond traditional group-level comparisons toward more individualized insights.

In addition, combining multiple methodological approaches appears to be especially valuable. Psychometric models provide reliable measurement of emotional regulation constructs, while dynamic and time-based models help explain how these processes evolve in real-world settings. Together, they offer a more complete and nuanced understanding (Hamaker et al., 2015).

Context also plays a critical role. Emotional experiences are shaped by everyday environments, social interactions, and cultural expectations. Studies using real-time data collection methods, such as experience sampling, show that emotional responses can vary significantly depending on situational factors (Shiffman et al., 2008). This highlights the need to study emotional regulation within the contexts in which people actually live and interact.

Recent advances in Machine Learning and Network Analysis have further expanded the field. These approaches allow researchers to identify complex relationships between emotional states and even predict how these states may evolve over time (Bringmann et al., 2013; Borsboom & Cramer, 2013). Such developments open new possibilities for both research and applied interventions.

Overall, this review suggests that emotional regulation is best understood as a complex, dynamic, and context-sensitive system rather than a fixed trait. This perspective not only

provides a more realistic understanding of human emotional functioning but also offers valuable directions for future research, assessment, and practice.

DISCUSSION

Interpreting Emotional Regulation as a Complex System

The major outcomes of this review strongly support the view that emotional regulation is not a simple, linear process but a complex, adaptive system. This perspective aligns with contemporary theories in psychology and systems science, which emphasize interaction, feedback, and emergence (Lewis, 2005).

By conceptualizing emotional regulation in manner, researchers can better account for the variability and unpredictability observed in real-life emotional experiences. This represents a shift from traditional models that focus on isolated strategies toward a more holistic understanding of emotional functioning.

Theoretical Implications

The integration of mathematical modelling into emotional regulation research has several important theoretical implications.

First, it challenges the assumption of stability that underlies many traditional models. Emotions are inherently dynamic, and understanding them requires methods that can capture change over time.

Second, it highlights the importance of context. Emotional regulation does not occur in isolation but is shaped by social, cultural, and environmental factors. Mathematical models that incorporate contextual variables offer a more realistic representation of emotional processes (Mesquita & Walker, 2003).

Third, it bridges the gap between different levels of analysis, from neural mechanisms to behavioral outcomes. Interdisciplinary approaches that combine psychological, computational, and neuroscientific perspectives provide a more comprehensive understanding of emotional regulation (Davidson, 2000).

Practical Implications

The findings also have significant practical implications across multiple domains.

- 1. Mental Health:** Dynamic models can enhance clinical practice by enabling early detection of emotional dysregulation and predicting relapse. For example, real-time monitoring of emotional states can help identify patterns associated with depression or anxiety, allowing for timely intervention (Wichers et al., 2010).
- 2. Education:** In educational settings, mathematical models can be used to track students' emotional engagement and identify those at risk of disengagement or stress. This can inform targeted interventions to support student well-being and academic success.
- 3. Organizational Contexts:** In the workplace, understanding emotional regulation dynamics can help organizations design interventions to reduce stress, prevent burnout, and enhance employee well-being. Predictive models can also support decision-making in human resource management.

Ethical and Cultural Considerations

While mathematical modelling offers powerful tools, it also raises important ethical and cultural concerns. One key issue is the potential reduction of complex emotional experiences to numerical data, which may oversimplify human reality.

Additionally, cultural differences in emotional expression and regulation must be carefully considered. Models developed in one cultural context may not generalize to others, highlighting the need for culturally sensitive research (Mesquita & Walker, 2003).

Data privacy is another critical concern, particularly in studies involving real-time monitoring. Researchers must ensure that data are collected and used responsibly, with appropriate safeguards in place.

Limitations of the Review

This review has several limitations. First, the included studies vary in methodology and quality, which may affect the consistency of findings. Second, the reliance on published studies may introduce publication bias. Third, the interdisciplinary nature of the field makes it challenging to achieve complete coverage of all relevant research.

Potential research trajectories

The future research should focus on:

- Integrating models across disciplines
- Using larger and more diverse samples
- Incorporating cultural variables
- Developing more interpretable computational models

Advancements in technology, such as wearable devices and artificial intelligence, offer exciting opportunities for further research in this area.

Conclusion of Discussion

Overall, this review demonstrates that mathematical modelling provides a valuable framework for understanding emotional regulation as a dynamic, context-sensitive process. By combining quantitative precision with psychological insight, these approaches offer new possibilities for both research and application. Mathematical modelling offers a powerful framework for understanding emotional regulation as a dynamic, adaptive system. While promising, it must be applied with sensitivity to human complexity.

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Mathematical Modelling of Emotion Regulation: A Dynamic Systems Approach to Understanding Psychological Processes

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Conflict of Interest

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