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Emotion dynamics

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The study of emotion dynamics involves the study of the trajectories, patterns, and regularities with which emotions (or rather, the experiential, physiological, and behavioral elements that constitute an emotion) fluctuate across time, their underlying processes, and downstream consequences. Here, we formulate some of the basic principles underlying emotional change over time, discuss methods to study emotion dynamics, their relevance for psychological well-being, and a number of challenges and opportunities for the future.

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To the astronomer studying celestial objects, the fact that planets and stars move in space is a matter of course, and forms the premise for all formulated principles, laws, and empirical observations. To the biologist, theories are formulated and observations are recorded grounded against the backdrop of knowledge that all life evolves across time and place. So too (should it be) for the emotion scientist, who studies phenomena that are not static, but continuously evolve, unfold, fluctuate, (de-)synchronize, linger, merge, and spillover across time. Theories on the nature of emotions from along the spectrum, from basic emotion theory over appraisal theories to constructionists accounts, readily acknowledge the dynamic nature of emotion [1–4]. Yet, for pragmatic reasons, emotion research has for long largely neglected the time dynamic aspects of emotions, mostly studying emotions as stable traits, or as brief states that simply switch on, stay, and switch back off (like a lightbulb) in response to events or experimental manipulation. In part spurred by calls from prominent theorists to place the dynamic nature of emotion center stage [5••,6–8], in recent years emotion science has increasingly taken to heart, into account, and into the lab, the fundamentally dynamic nature of emotions.

The study of emotion dynamics involves 'the study of . . . the trajectories, patterns, and regularities with which emotions, or one or more of their subcomponents (such as experiential, physiological, or behavioral components) fluctuate across time, their underlying processes, and downstream consequences' [9, p. 71]. While the aim or object may overlap in varying respects with that of other areas in emotion science, such as research on affective chronometry [5••], emotion regulation [10], or the context-dependent nature of emotion [11], the common denominator of research on emotion dynamics is the explicit recognition that a thorough understanding of the nature, causes, and consequences of emotions entails explicitly taking into account the dimension of time.

What have we learned from this field so far? In this brief (admittedly idiosyncratic) overview, we formulate some of the basic principles underlying emotional change over time and the patterns they give rise to, discuss methods to study those principles and patterns empirically, review their implications for psychological functioning and well-being, and discuss some of the challenges and opportunities that lie ahead in the future.

What's the time? Principles of emotion dynamics

In what follows, we describe what we see as the core principles involved in emotion dynamics, based on findings from research examining the ways emotions change across time.

A first principle states that emotions consist of responses to things extrinsic to them (*principle of contingency*). In normality, emotions are typically contingent on internal or external events, often social in nature [2,59], that touch on our concerns and well-being [60]. As these events, or rather appraisals or constructions of them [1,3] change or unfold, so do emotions.

At the same time, emotions are intrinsically governed by two opposing forces. On the one hand, emotional states display an intrinsic resistance to change, even in the presence of forces that motivate change, causing them to display a general tendency to carry over from one moment to the next (*principle of inertia*; [12•,13]). Such inertia arises from the fact that we tend to perceive and interpret the world around us in ways congruent with our current emotional state [61–63].

On the other hand, emotions are continuously regulated to maximize fit with the current desired state (*principle of*

regulation). Most typically this takes the form of down-regulating emotions to prevent them from lingering endlessly or to dangerous extremes [10,14,15], but can also take the form of upregulating emotions in anticipation of circumstances in which their mobilization may help to achieve a current goal (such as in instrumental regulation; [16]). From this, it also follows that the current desired state, and the regulation needed toward it, may also change across time (referring to allostasis, see e.g., [17,18]). The balance between these two opposing forces, the tendency to resist change and the tendency to continuously regulate to achieve optimal fit, determines to a large extent how an individual's emotions unfold across time, and how emotions may become aberrant (see below).

Finally, the components of emotions (physiological, experiential, behavioral), or the emergent emotional states as they are experienced as a whole, continuously interact with, augment and blunt one another, creating a system that displays evolving patterns of (a)synchrony and networks of interacting elements (*principle of interaction*). In the case of interactions between emotion components (e.g., the mutual relations and interactions between physiology, experience, and behavior during emotions), such interactions for instance lie at the base of the notion of synchronization or response coherence thought to be a fundamental defining feature of emotions (e.g., [19••,20]), although evidence for the existence of strong synchronization remains lacking [21,22]. In the case of interactions between different emotions, for instance the level of correlation between the experiences of different emotions is considered to reflect the extent to which people make very coarse or very fine-grained distinctions between different emotional states in their experience, labeled emotion granularity or differentiation (e.g., [64]).

In sum, these principles together identify the major principles involved in the dynamics of emotions, and delineate the boundary conditions to which normal adaptive functioning of our emotion system should adhere. Emotions do not arise on their own but result from changes in the internal or external, often social environment. Fluctuations in emotions result from balancing self-preservative and regulatory tendencies, and are in constant interaction with the fluctuations in other emotions or emerge from interactions between emotion components themselves.

The principles also hint at some of the key dynamical characteristics we can look for (and study) in emotions. In Kuppens and Verduyn [9], we give a systematic overview of different types of patterns of emotional change, both within single episodes and of emotion trajectories across longer periods of time, that are in essence the emergent properties of the principles outlined above. Such characteristics are the duration (e.g., [23••]) and shape of an intensity profile of single emotional episodes (e.g., [5••,24,25••]), and the level of variability (e.g., [26]), inertia (e.g., [13]), covariation or granularity (e.g., [27,64]), and cross-lags (e.g., [28]) between emotions or their components display over time (see [9], for a detailed overview). Table 1 provides a list of these features with their description and calculation.

Empirical study: timely opportunities

How can such characteristics be studied? Studying emotion dynamics requires making sense of by definition intensive longitudinal data that document relatively short-term changes[3] in emotion (components) across time, either in standardized lab or in real life settings. Luckily, we are currently witnessing a revolution in this respect that is gaining ground on two crucial fronts. First, the methods to collect such data, involving both data collection and processing of real time behavior, emotional facial and vocal expression, peripheral and central physiology in the lab [29] as well as methods to study (at least some of) these elements in real life [30,31], are becoming more and more part of the standard toolbox of emotion scientists. Hand in hand with these developments, methods to analyze and model the resulting complex data are increasingly being developed and made available to emotion scientists (for a recent overview, see e.g., [32••]). Combined, these developments hold large promise for the future of emotion (dynamics) research, both when it comes to uncovering basic mechanisms and processes, as well as in terms of practical applications in applied domains (see e.g., [33••]).

Good times? Relation with well-being

The emotions we experience are not without consequences but determine for a large part mental flourishing and suffering. On the bright side, psychological well-being relies greatly on how people experience positive and negative emotions in their lives (e.g., [34]). On the dark side, emotions play a pivotal role in various forms of psychopathology, particularly mood disorder. When the US National Institute of Mental Health released its Research Domain Criteria (RDoC) to be targeted by scientific effort to enforce much needed progress in the study of mental disorder [35], 3 out of the 5 domains center around emotional processes (negative valence, positive valence, and arousal and regulation). Furthermore, as it has become apparent that mood disorders constitute a huge burden on society [36], understanding the pathogenic processes at play is of paramount importance.

How can we understand the relation between emotion and psychological well-being? We argue that looking at emotions from a dynamical perspective may allow to bring this relation into sharp focus. Indeed, the emotion

[3] To distinguish emotion dynamics from developmental changes.

Table 1

Overview of a number of emotion dynamic features, their description, and calculation.

Emotion dynamic feature	Description	Calculation
Feature of emotional episode		
Duration	Elapsed time between the start and end of an emotional episode	Time difference between start and end of emotional episode
Intensity profile shape	The shape of fluctuations in emotional intensity during an emotional episode	fPCA component scores, K-SC cluster membership.
Feature of emotional trajectory		
Emotional variability	The range or amplitude of emotion fluctuations	Standard deviation or variance of emotion (component) across time
Emotion (component) co-variation (differentiation/granularity)	Degree of covariation of emotions across time	Mutual intercorrelations or Intra-Class Coefficient of multiple emotions (components) across time
Emotional inertia	Degree with which an emotion (component) carries over from one moment to the next	Autocorrelation (or autoregressive effect) of emotion (component) across time
Emotion augmentation and blunting	The degree to which an emotion (component) predicts another emotion (component) across time	Cross-lag correlation (or crossregression effect) between emotions across time

dynamics principles we defined at the outset of this project may provide a crucial window to understand what constitutes adaptive and maladaptive emotional functioning. There is strong evidence that maladaptive emotional functioning reflects dynamic emotion patterns transgressing the normal boundaries dictated by the principles outlined above. With regards to the principle of contingency, both excessive and blunted emotional reactivity to events is thought to underlie various forms of mood disorder such as depression and bipolar disorder [37–39]. With regard to the principles of inertia and regulation, in a recent meta-analysis, we demonstrated how on the one hand high levels of emotional variability, but on the other hand also too high levels of emotional inertia, are consistently linked with various indicators of ill-being and forms of psychopathology such as depression, bipolar disorder, and borderline personality disorder [40••]. With regard to the principle of interaction, emotion components or states form more dense networks and interactions across time in for instance depression or depressive vulnerability [41,42], reflecting an emotion system that is more self-predictive, less open to outside influences, and therefore less flexible, effectively decoupling it from the adaptive nature our emotions are designed for.

The above findings raise a fundamental question about the role of emotion dynamics in well-being and maladjustment. Are dynamical patterns merely a surface phenomenon, or could they rather play a more causal role in the development and maintenance of well-being and maladjustment?

On the one hand, the ways with which a person's emotions fluctuate across time may be a concomitant or consequence. For instance, psychological health may offer an individual the resilience and adaptive coping mechanisms to keep one's emotional responses in check, resulting in appropriate levels of emotional reactivity or more adaptive emotional interactions across time (such as positive emotions blunting the effects of negative emotions; [43]). In contrast, depressive mood may slow down the way a person's emotions unfold across time, leading to higher levels of inertia [44].

On the other hand, specific patterns of emotion dynamics may reflect early warning signs of emotional dysregulation that create vulnerability to disorder and maladjustment, or may help to maintain or create well-being. High emotional inertia or high facilitation (interaction) between negative states may create an adverse emotional life that may become increasingly difficult to control, resulting in a downward spiral of emotional dysfunctioning. Inappropriate emotional variability at the micro-level may accumulate into emotional wear and tear, leading to macro-level forms of psychological illness. Alternatively, the presence of dynamical patterns that allow for flexible adaptation (such as lower inertia or adaptive emotion interactions) may help to maintain well-being and provide a protective buffer in times of stress (see e.g., [25••,45•], for similar theoretical perspectives). Supporting such a view, in a seminal study, we demonstrated that emotion dynamical patterns reflective of the principles outlined above act as early warning signs for the onset and offset of major depressive disorder ([46•]; see also [47]). Wichers and Groot [48] recently illustrated this at a within-person level. More recently, Husen *et al.* [49] showed how emotion dynamics prospectively predict response to treatment in a sample of participants suffering from depression. In short, evidence is accumulating that emotion dynamics are not just a mere concomitant of psychological well-being and maladjustment, but may reflect early protective or risk factors to develop mental flourishing or suffering across longer periods of time.

Challenges and opportunities in times ahead

On a basic science level, many questions remain to be addressed, making emotion dynamics research a fertile ground to plough for aspiring emotion researchers. How do people integrate information from the events they encounter and their internal world that gives rise to changes in feelings (e.g., by predictive coding; Barrett, in press)? How are emotion dynamics a function of contextual factors and individual differences (e.g., in terms of reactivity and regulation through attractors states; e.g., [13])? Do the neural correlates of emotional experience vary throughout an emotional episode (this seems to be the case; [50]), and how is emotional flexibility or rigidity produced in the brain (e.g. by adequately, resp. inadequately matching valuations to motivational states; [51,52••])? How do emotions unfold and interact between people and what does this tell us about individuals and relationships (e.g., healthy interpersonal relationships are characterized by reciprocal emotional co-regulation; [53••,54••])? How do emotion dynamics evolve through the lifespan (e.g., by becoming more stable; [55])? These are just some of the questions that emotion dynamics research can and hopefully will address. Moreover, expanding our insight in how emotions change across time will allow for more precise predictions about their role in other phenomena such as perception, memory, physical and mental health. Also on an applied level, we envision that taking the dynamical nature of emotions into account will prove fruitful in diverse domains such as human-computer interaction [56], workplace behavior and well-being [57], mobile sensing (e.g., [30]), prediction and treatment of mood disorder and mobile mental health [58••] and so on. The time is now for emotion dynamic research.

Conflict of interest statement

Nothing declared.

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