

Is there evidence for sensitive periods in emotional development?☆

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During sensitive periods an individual's development is especially receptive to information from the environment in ways that it is not at earlier and later developmental stages. Here, we describe challenges in applying the concept of sensitive periods to the domain of socio-emotional development, review what applications of this approach have accomplished, and point to promising future directions. We also argue that since emotional development consists of higher-order cognitive processes, it likely involves multiple and overlapping sensitive periods tied to different mechanisms (e.g. facial recognition, reward processing, fear conditioning). Moreover, we note a distinction between the construct of a sensitive period versus the identification of an effect of early experience — two ideas that are often confused in the literature. Progress in the study of emotion will require understanding the mechanisms involved in developmental change and models that predict children's behavior based on their prior experience.

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Sensitive periods are developmental time periods when individuals are especially receptive to, and influenced by, input from their environment [1–3, see Ref. 3 for a discussion of what we mean by input from the environment]. The concept of a sensitive period does not imply that neural functions or overt behaviors are not influenced

by input before that period, that they cannot be changed later in development, or that changes that occur during sensitive periods are fixed or irreversible. Rather, the idea is that sensory input is likely to have a greater influence on some biobehavioral systems during particular developmental stages. Sensitive periods are often contrasted with critical periods, with the latter making stronger claims about the ability of learning to take place outside of specified time periods. While this review will focus on sensitive periods, we believe the same criticisms and approaches can be applied to critical periods.

There are a number of ways in which the concept of sensitive periods — if valid — can be helpful. For example, better understanding of developmental periods can account for why the emergence of certain behaviors tends to follow milestones or stages, why certain aspects of development might need to precede acquisition of other skills, or why perturbations of an environment typical for a species can influence an individual's subsequent development. Identifying and validating sensitive periods may also have practical implications for child development. Better understanding of these periods of sensitivity to input can be helpful for guiding policy and interventions, especially for cost-benefit types of decisions regarding when delivery of an intervention, implementation of a prevention program, or provision of certain experiences might have greatest impact on children's development. However, for the construct of sensitive periods to be meaningful (and empirically falsifiable), they must be formulated in such a way that they are related to specific aspects of subsequent behavior. Below we briefly summarize how the concept of sensitive periods as been applied to the domain of emotional development, highlighting aspects of the literature that have been relatively successful as well as where research in this area has been limited. Here, we make two points. First, that since emotion is an emergent property of multiple higher order processes, the study of sensitive periods in emotion development requires a focus on discrete processes subserving emotion-related behaviors. And second, that in the developmental literature any negative early experience that has a long term effect is often erroneously construed as evidence for a 'sensitive period.' An argument in support of a sensitive period must demonstrate that input during particular developmental

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periods and not others, leads to substantive changes that would not otherwise occur. Although we do yet see robust evidence in the literature for sensitive periods in emotional development, we do not conclude that sensitive periods do not exist. Rather, our point is that more data is needed to understand which mechanisms might open, close, or extend sensitive windows in development with implications for specific socio-emotional behaviors.

A brief overview of the study of sensitive periods of socioemotional development

Much of the work on sensitive periods in emotional development has focused on children with atypical caregiving experiences, such as children raised in institutions rather than families. This type of research has been invaluable for understanding the importance of caregiving environments on children's development. Raising children in these circumstances can have long term impacts on children's stress response systems including disruptions to their autonomic nervous system functioning [4], brain development, emotion regulation [5–7], and mental health [8,9*]. Other work on sensitive periods in emotional development has focused on the role of children's neural development [10,11], particularly how the development of prefrontal and amygdala circuitry [12,13] may be influenced by extreme adversity [14]. While this literature is thought-provoking and raises many compelling questions about human development, there are some important limitations that apply to some of these approaches generally.

Challenges in the study of sensitive periods of socioemotional development

Although the concept of sensitive periods in development can be alluring, it is difficult to evaluate the soundness of this phenomenon in humans across domains. There are a number of challenges specific to establishing the existence of sensitive periods for emotion. First, sensitive periods are often evoked in a way that implies that emotion (or social behavior, as with the term 'socio-emotional' development) is one system, with one sensitive period that might affect all of emotional behavior. This is unlikely. A domain of development where extensive empirical research on sensitive periods has been undertaken is language. But there is no sensitive period for 'language' as a broad construct. Rather, language is a higher-order system with multiple sensitive periods for specific aspects of processes related to language acquisition [15**]. For instance, there is evidence for a sensitive period for some aspects of syntactic rules [16], and *multiple* sensitive periods relating to phonology and phonemic discrimination [17,18]. Yet there is no evidence of a sensitive period of vocabulary acquisition, or the ability to process most aspects of syntax in simple sentences (though there is debate surrounding this issue, see Refs. [19,20]). The study of sensitive periods in emotion development is often applied in an overly broad way, rather than in terms of the different components that constitute emotion processing.

Emotional development likely emerges from multiple, overlapping systems each of which might have its own set of sensitive periods or no sensitive periods at all [21]. In navigating their social worlds, children learn to discriminate and categorize perceptual cues of emotion, label actions and experiences as emotions, make inferences about what others think, feel, and are likely to do next, make sense of their own experiences, learn social display rules, and regulate their feelings and behaviors in accord with environmental circumstances. These processes require multiple attentional processes, memory and categorization abilities, processing of biological motion, accessing of conceptual and lexical knowledge, response generation and impulse control — just to name a few. Processing of facial and bodily emotion cues relies upon the visual system, emotional prosody is tied to the auditory system, and many expressive and regulatory behaviors require maturation of motor systems. Therefore, any sensitive periods in emotion will likely apply to some subset of these discrete processes, and different processes may each have different sensitive periods.

A second conceptual problem in the extant literature is confusing a sensitive period with an effect of early experience in development. These concepts are not synonymous and confer different implications for understanding human development [22]. There is now ample evidence that perturbations in caregiving or extreme levels of adversity have cascading effects on many aspects of children's socio-emotional development. But evidence that adversity is associated with heightened risk of negative outcomes is not sufficient in and of itself to claim that the behavioral sequelae of these effects resulted from a sensitive period. A sensitive period requires that the environment has an especially large impact on development that it would not have at later or earlier ages. To be useful, the concept of sensitive periods requires precision. For example, to say that early experience of adversity puts children at risk for a range of behavioral, educational, and health problems highlights a role of adversity in child development, but not a sensitive period. A correlation between an early event and a negative outcome does not specify a developmental window of vulnerability, a process through which that window of vulnerability becomes opened and closed, or a hypothesized specific mechanism being disrupted by one particular experience that leads to a prediction for a high likelihood of a particular outcome. Moreover, the observations that some individuals who have the same experience at the same developmental stage may develop particular outcomes whereas others may not, may be better suited to an early experience model than to a sensitive period model.

Related to this issue, much of the work on early adversity is not able to separate out effects of timing versus effects of dose. For example, Romanian children who spent less than six months in institutions did not demonstrate the

same degree of negative outcomes as did children who spent longer than six months in institutions [23,24]. These differences in outcomes could be because of the timing of the negative events (e.g. stressors before year one may not be a sensitive period but stressors after this period are). Alternatively, these effects may be attributable to the total accumulation of negative experiences (those who spent longer than six months in institutions had more negative experiences over a longer time). Modeling [25*,26,27] and longitudinal [28,29] approaches could be one way to try to tease apart these different possibilities with the caveat that, even with incredibly rich datasets, researchers have had low success rates predicting life outcomes [30].

Progress and future directions

Despite the above challenges in the study of sensitive periods, there are many promising future directions that researchers can use to overcome these challenges (see Table 1). Non-human animal research may help address many of the above criticisms, as it is possible to cleanly manipulate the timing and type of stimuli that animals encounter over their early development (for an overview of the empirical designs used in this type of research see Ref. [31]). However, some phenomena, such as development of binocular vision or depth perception, are amenable to empirical validation of sensitive periods because discrete processes such as the spectral sensitivity of rods and cones can be isolated and measured in ways that map directly onto behavior. In contrast, emotion appears to be sets of emergent properties arising from multiple processes, each with its own maturational period. Some aspects of emotion, such as fear conditioning and stress regulation translate well between humans and non-human animals [32**], while other aspects of emotion such as subjective feelings or accurate inferences of others' feeling states are difficult to compare across species. Translation across species also raises the issue that not all scientists may agree on what constitutes emotion. Some may see stress physiology as a window into emotion, but others may not; some see emotions as part of human consciousness and lacking animal correlates,

others do not (see Ref. [33*] for a summary of these different viewpoints).

A key component of applying the construct of sensitive periods is understanding what factors might 'open' and 'close' windows of sensitivity (see Ref. [15**]), and what the outcomes of these shifts in windows might be, rather than only focusing on whether or not a sensitive period exists. Some aspects of development can be disturbed if expected input never occurs during particular windows. For example, multiple critical and sensitive periods for vision exist where the lack of expected input can impair brain structure and function. However, experiences can also change when the windows for sensitive periods occur. Not receiving the expected input from the environment can sometimes delay and extend these periods [1]. For instance, when animals are raised in darkness it slows down the progression of certain sensitive periods in vision [34], and even reopens these periods of sensitivity [35]. This concept raises many interesting questions about the nature of sensitive periods in emotional development. What might cause these windows to stay open longer (or even reopen) in an emotional context? How do delays and changes in caregiving impact the timing of these windows? Can extreme social isolation and deprivation have an impact akin to dark rearing?

One way to better understand these windows of sensitivity is to continue to assess children's development across the lifespan. For instance, adolescence may be an important factor in the opening or reopening of various sensitive periods in emotional development. Postinstitutionalized children followed across development show atypical HPA axis functioning at younger ages, but this difference disappears in adolescence as children live in stable environments [36]. This recalibration could be because adolescence is an additional sensitive period that allows the individual to recalibrate to the environment (e.g. Refs. [37–39]). Or, this could reflect a reopening of an earlier sensitive period, or a shifted window (e.g. a window that opened later and closed later or that stayed open longer), or continued plasticity that is not the result of a sensitive period at all. Better understanding of these windows may

Table 1

Summary of recommendations in the study of sensitive periods in emotional development

Recommendation	Example
Focus on discrete processes in emotion development	We suggest exploring the possibility of multiple, overlapping critical and sensitive periods for different processes like reward learning, fear conditioning, and comprehending emotional prosody (see Ref. [15**] for a discussion of this approach in language)
Focus on what opens, closes, and extends sensitive windows	See Ref. [36] for a discussion on how adolescence may influence sensitive windows
Use animal models to illuminate specific mechanisms when possible	See Ref. [32**] for a discussion of this process in fear conditioning
Modeling as a way to try to disentangle processes	See Ref. [3] for a discussion of modeling approaches generally and See Ref. [25*] for an example this approach

explain the heterogeneity in outcomes for children who lived in institutions for extended periods of time. While many children suffered severe impairment, 20% of adoptees in an adult follow-up study were ‘problem-free at all assessments’ [24]. Being able to explain why these early experiences impacted some children but not others is a crucial part of the case for sensitive periods and their implications for policy and intervention.

Another way to begin to gain traction in the domain of emotion is to generate and test specific mechanisms. Thus, rather than studying whether there is a sensitive period for a broad construct like ‘socioemotional learning,’ one could interrogate sensitive periods for component processes of emotion learning such as fear conditioning, facial recognition, reward processing, or processing of emotional prosody. One promising line of work has focused on children’s learning of cues of threat and safety (as one piece of socioemotional learning). Much of this work is based on children’s ability to form initial social relationships with others or ‘attachments.’ We want to clarify that we are not using attachment in the specific way tied to a particular theory or method, but more to denote social bonding, secure base behavior, and infants establishing a sense of security or protection in the presence of others. This attachment is believed to play an important role in how children learn to disentangle cues of threat and safety (though see Ref. [40] for a discussion of what it means for infants and young toddlers to experience ‘fear’).

Recent work suggests that infancy may be a sensitive period for an individual to learn to identify signals of safety, as these safety cues engage prefrontal inhibitory circuits that prevent threat perception [41]. Caregiver maltreatment and deprivation during this period may impair children’s ability to learn cues of safety, and accelerate learning of threat cues [6,42,43]. These changes in learning may lead children to have generalized feelings of unsafety [44]. In contrast, in a typical caregiving environment, caregiver presence can often block the learning of threat [45]. Similarly, parental presence in humans can cause children to switch from avoidance learning to attraction learning [46]. Thus, in early development caregivers consistently act as signals of safety as their presence decreases the impact of a stressor on young children (e.g. Refs. [47,48]). Over time, the parental relationship and periods of transient and extended exploration allow children to learn to disentangle cues of threat and safety (see Ref. [32**] for a detailed and elegant discussion of these phases and their correlates in human and animal research). On this view, disruptions to care during this hypothesized sensitive period may result in lasting changes to these systems that would not occur at later ages, such as an earlier transition to adult-like fear learning [49,50]. In this manner, the construct of attachment highlights

success in the study of sensitive periods by using animal models to examine more specific mechanisms and more cleanly manipulate the timing of input, focusing on specific mechanisms generally, and testing these effects in children in meaningful ways.

Conclusion

Identifying and confirming the existence of sensitive periods for socio-emotional development in humans poses both methodological and conceptual challenges. Emotion likely involves multiple processes with overlapping periods of development, each tied to the emergence of a different, relevant function. Animal research, when tied to human behavior in a meaningful way, is a powerful tool to guide this research and uncover mechanisms that would be difficult to find using human research alone. However, this process becomes even more challenging when examining more uniquely human behaviors (e.g. subjective emotional experience, verbalizing other’s emotional states).

Human research on sensitive periods of emotional development has also often equated any effect of early experience as a sensitive period. However, a sensitive period requires that the environment has an especially large impact on development that it does not have at earlier and later ages. An early experience having a behavioral impact is not sufficient in and of itself to suggest a sensitive period. Furthermore, much of human research on sensitive periods has been done on children who have had species atypical caregiving experiences. These periods of exposure are not so sharply defined and often involve multiple types of unusual experiences.

One way to overcome these challenges is to focus on a singular process or mechanism that explains one part of emotional development. Work on children’s learning of cues of threat and safety has benefitted from this approach through using animal models in meaningful ways. This connection has also worked to uncover the causes of the onsets and offsets in sensitive periods relating to fear learning, and what can change the timing of these windows. Crucially, this approach has led to predictions about what children’s behavior should look like based on their prior experiences.

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