Review

# Sensory emotion regulation

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Decades of evidence reveal intimate links between sensation and emotion. Yet, discussion of sensory experiences as tools that promote emotion regulation is largely absent from current theorizing on this topic. Here, we address this gap by integrating evidence from social-personality, clinical, cognitive-neuroscience, and animal research to highlight the role of sensation as a tool that can be harnessed to up- or downregulate emotion. Further, we review evidence implicating sensation as a rapid and relatively effortless emotion regulation modality and highlight future research directions. Notably, we emphasize the need to examine the duration of sensory emotion regulation effects, the moderating role of individual and cultural differences, and how sensory strategies interact with other strategies.

*Nothing can cure the soul but the senses…*
Oscar Wilde

## The senses: a (surprisingly) often overlooked emotion regulation modality

The *taste* of ice cream soothes a broken heart.

The *sound* of electronic music energizes an athlete before a big game.

The *sight* of a wondrous piece of art helps put one's problems in perspective.

The *smell* of baking bread evokes a sense of pleasure.

The *touch* of a loved one's hand eases anxiety after a stressful day at work.

Throughout history, cultures around the world have turned to their senses to manage emotions. Ancient Chinese civilizations used aromatic essential oils to treat insomnia [1], Egyptian healers living during the time that the Giza pyramids were built applied gentle touch on their patients' feet to ease tension [2], and, in Ancient Greece, Plato soliloquized about the power of music to positively transform negative emotional states [3]. Indeed, the use of **sensation** (see Glossary) to modulate emotion is far from a new phenomenon. On the contrary, it is a tool that cultures have relied on for millennia.

Fast-forward roughly 6000 years. Scientific research has revealed robust links between sensation and emotion. In fact, as we review in more detail below, one of the most powerful tools that **affective scientists** have in their arsenal for activating emotions is the senses: they frequently expose people to carefully selected images and sounds to elicit strong emotional reactions [4]. Yet, contemporary models of **emotion regulation** largely fail to consider the role of sensation as a tool people use to modulate their emotions (Box 1). In this vein, consider the fact that, of the five most cited review papers on emotion regulation published over the past 6 years [5–9], not one

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> **Box 1. Contemporary frameworks of emotion regulation**
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> Emotion regulation involves conscious and unconscious attempts to influence the duration, intensity, and quality of emotions [7]. Multidisciplinary research on emotion regulation has grown exponentially over the past two decades and multiple models have been proposed. Despite the popularity of these frameworks, there remains vast diversity in the conceptualizations they advance [115].
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> The **process model of emotion regulation** [115,116], arguably the most prominent model, distinguishes between five families of tools: situation selection (e.g., approach/avoidance of a situation), situation modification (e.g., changing emotion-eliciting facets of a situation), attentional deployment (e.g., attending to different aspects of the situation), cognitive change (e.g., changing the way we think about a situation), and response modulation (e.g., changing behaviors caused by the situation). However, both the original process model and the extended model are silent concerning the role of sensory experiences in emotion regulation [115,116].
>
> Other popular frameworks likewise fail to mention sensation. One framework categorizes emotion regulation strategies as either adaptive (e.g., acceptance or reappraisal) or maladaptive (e.g., rumination or expressive suppression) [117]. Another framework distinguishes between implicit (e.g., affect labeling) and explicit (e.g., reappraisal) forms of emotion regulation [5]. However, both of these frameworks also fail to discuss sensory tools [5]. Yet another framework that examines common structures underlying emotion regulation tools notes that 'one could regulate emotions by eating or restricting food intake', but does not elaborate on whether the mechanism underlying this effect is sensation or some other facet of eating such as the satiation or inhibition of desire (see p. 385 in [7]).
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> In sum, the aforementioned models have provided the field with invaluable frameworks to study emotion regulation but can be enriched by integrating the role of sensation into their conceptual spaces.

mentions sensation as an emotion regulation tool. This omission is particularly surprising given the role of sensation in many clinical treatments for emotional disorders. For example, mindfulness-based stress reduction programs direct people's attention to the sensations they are experiencing to cultivate self-awareness [10], progressive muscle relaxation techniques guide people to tense and relax muscle groups to reduce stress [11,12], and dialectical-behavioral therapies heighten people's awareness to the sensory properties of food to help them savor emotional experiences [13].

Here, we address this omission by integrating evidence from social personality, clinical, cognitive-neuroscience, and animal research to highlight the role of sensation as a simple, effective, and potentially effortless emotion regulation tool. We begin by describing the inextricable links that characterize the relationship between sensation and emotion. Next, we review experimental evidence indicating that people strategically activate their senses to up- and downregulate emotions. We then discuss the possibility that sensation provides a relatively effortless route to emotion regulation. We conclude by describing the potential basic science and practical implications of integrating the study of sensation into emotion regulation.

## Sensation and emotion are inextricably linked

Sensation allows us to quickly detect information about our physical surroundings [14]. Without it, we would be incapable of successfully navigating the world; gone would be our ability to discern a friendly greeting from a fire alarm, a paved street from a pothole, or salubrious fruit from rotten milk.

Although the precise number of sensory modalities we have is an ongoing topic of debate [15], a common pathway governs how they operate at a broad level. Environmental stimuli activate sensory organ receptors (i.e., the eyes, ears, skin, tongue, and nose), which transform physical energy into neural impulses. These electrical signals are then transmitted through the central nervous system to the brain, which interprets, organizes, and makes meaning of incoming sensory information [14].

It is important to note from the outset that sensation need not involve emotions. For instance, the touch of your pants and the sound of cars passing by on a quiet street is unlikely to meaningfully influence your emotions. Yet, both common experience and research indicate that many of our

## Glossary

**Acceptance:** emotion regulation strategy that involves maintaining an open and nonjudgmental attitude toward one's emotions and thoughts.

**Affective scientists:** scholars across a variety of disciplines (e.g., psychology, neuroscience, sociology, anthropology, law, and political science) who study emotion.

**Binge eating:** consuming unusually large amounts of foods in a short period of time, particularly those high in calories, fat, or sugar.

**Cortisol:** hormone with a key role in the response of the body to stress. In emotion research, cortisol levels are often used as physiological indicators of stress.

**Dopamine:** neurotransmitter that is primarily associated with feelings of pleasure.

**Electroencephalogram (EEG):** methodology that assesses electrical activity produced by neurons in the brain by attaching electrodes to the scalp; used to evaluate brain disorders and assess neural responses to stimuli.

**Emotion regulation:** process by which individuals consciously or subconsciously influence which emotions they have, when they have them, and how they experience them.

**Event-related potential:** electrical brain response resulting from a specific cognitive, sensory, or motor event.

**Expressive suppression:** emotion regulation strategy wherein one deliberately attempts to hide or reduce expressions of emotion (e.g., a frown or tears).

**Process model of emotion regulation:** prominent model of emotion regulation that distinguishes between five families of regulatory tools: situation selection, situation modification, attentional deployment, cognitive change, and response modulation.

**Reappraisal:** emotion regulation strategy that involves reinterpreting the meaning of a stimulus or situation.

**Rumination:** emotion regulation strategy that entails thinking repeatedly about negative experiences in ways that perpetuate distress.

**Self-distancing:** regulatory strategy that involves adopting a perspective of a distanced observer (akin to a fly on the wall) when thinking about past or current experiences.

**Self-injurious behavior:** consciously engaging in behaviors that result in

sensory experiences are infused with emotion. Indeed, part of the reason why sensation is so remarkably effective at informing us whether to approach or avoid stimuli is because of its ability to activate brain networks that produce emotional responses. This is true of each of the sensory channels. Once incoming sensory input reaches the appropriate **sensory cortex** (i.e., auditory, visual, gustatory, olfactory, or somatosensory), neural signals project rapidly and directly to brain regions that are centrally involved in generating emotional responses, such as the amygdala, insular cortex, and orbitofrontal cortex, which help people quickly determine whether stimuli are pleasant/safe or unpleasant/threatening [16–18]. These sensory–emotion pathways allow us to respond to stimuli in ways that promote our safety (e.g., fleeing upon smelling fire).

The ability of sensation to activate brain regions that support emotional processing is crucial for survival. For instance, upon detection, tastes are immediately encoded as appetitive or aversive to promote nutrition and survival [19,20]. Bitter and sour tastes ensure that poisonous and rotten food is not ingested [21], and sweet and salty tastes ensure that our bodies receive crucial nutrients (e.g., carbohydrates) [22]. Further, the hedonic tone of a sound or odor guides adaptive behaviors in response to threat [23,24]. In sum, part of why sensory input rapidly activates emotion is to promote survival.

Taken together, these diverse sets of findings demonstrate that the process of sensation is intimately linked with our experience of emotion. Furthermore, evidence indicates that sensation can also influence emotion via indirect pathways, such as diverting attention, promoting cognitive reframing, and activating autobiographical memories (Box 2). We next explain how this relationship can be harnessed to provide people with a tool to manage their emotions.

## Harnessing sensation to regulate emotions

A key element of our argument is that sensation can be harnessed as a tool that people deliberately wield to manage their emotions. This suggests that sensation does not only activate emotion passively, as when a person stumbles on a negative scent or sound while walking down a city

physical injury to one's own body. These include, but are not limited to, cutting, burning, or severely scratching one's skin.

**Sensation:** process by which our sensory organs receive information about the physical environment.

**Sensory cortex:** set of cortical brain areas responsible for receiving and processing sensory information gathered by our sensory organs (e.g., eyes, nose, ears, mouth, and skin).

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**Box 2. Indirect pathways from sensation to emotion**

Although sensation can directly influence emotions by activating brain networks that support emotion generation and regulation, it can also influence emotions indirectly through at least three other pathways.

First, sensory experiences can serve as a distraction. For example, auditory stimuli, such as music, ease preoperative anxiety in patients awaiting surgery by diverting their attention away from their upcoming procedure [118]. Other examples include binge eating and engaging in self-injurious behaviors, both of which have consistently been found to serve a distraction function, diverting people's attention away from negative emotional experiences [119,120].

Sensation can also influence emotions by helping people cognitively reframe negative experiences. For instance, people often seek sensory stimuli (e.g., music) to gain acceptance of their feelings [111] and to **self-distance** from their situation and remind themselves of the bigger picture [121]. In addition, holding a loved one's hand promotes cognitive reappraisal during unpleasant emotional states [42]. Finally, young children can more successfully reframe their fear responses to negative stimuli (e.g., photographs of a poisonous snake) when they can see their parents in the room [122].

A third way sensation modulates emotion is through memory. The bulk of the work in this domain has focused on how pleasant memories triggered by sensory input elicit positive emotion. For instance, old photographs are particularly rich cues for retrieving positive memories [123]. Memories evoked by music, which occur involuntarily in everyday life, can produce positive emotions and feelings of nostalgia [124]. Eating food associated with sentimental memories reduces stress [125], while smelling odors that evoke positive autobiographical memories increases positive emotion and decreases physiological indicators of stress [126]. Of course, the inverse is also true; sensory stimuli associated with negative autobiographical memories can activate unpleasant emotions.

In sum, sensation can impact emotions via a host of indirect pathways. This highlights the need to understand not only how sensation operates on its own, but also how it interacts with other strategies and regulatory processes to modulate emotion.

street. It implies that our sensory apparatus can also be volitionally activated to shape emotional experiences. In this section, we review crossdisciplinary evidence supporting this assumption for each of the five major sensory modalities. We focus exclusively on experimental evidence because experiments, by design, involve the strategic activation of sensory inputs. Thus, they provide proof-of-principle evidence indicating that sensation can be strategically harnessed. We also provide evidence demonstrating that people deliberately seek sensory stimuli in everyday life to achieve their regulatory goals.

### Sound

One of the primary reasons why people choose to listen to music in their everyday lives is to regulate their affect [25,26]. A large-scale international study (N>7500) found that 90% of people use music to relax, 82% use music to feel happy, and 47% use music to process or release sadness [27]. Are such efforts effective? Decades of research highlight auditory stimuli, such as music, as an effective tool to increase positive emotions (e.g., happiness and relaxation), reduce negative emotions (e.g., anxiety and anger), and impact motoric reactions associated with emotion (e.g., facial expressions) [28]. Listening to music alters physiological experiences of stress, including heart rate, blood pressure, and **cortisol** levels [29], and facilitates physiological stress recovery [30]. Music can also evoke pleasure by activating dopaminergic mesolimbic reward pathways [31]. These effects of music on emotion are substantial. A meta-analysis of nearly 50 music therapy interventions found a medium-to-large effect of music therapy on stress and related emotional outcomes [29].

### Smell

Odors elicit a full range of emotional experiences (including fear, joy, disgust, and surprise) and impact physiological and behavioral indicators of emotion [32,33]. In humans, experimental research demonstrates the direct effects of olfactory stimuli, such as wood [34], roses [35], and orange essential oils [36], on self-reported and physiological stress. In addition, the smell of a romantic partner (via a t-shirt) reduces both self-reported stress and cortisol levels during stressful laboratory tasks [37]. In animals, mice experience significant reductions in anxiety when exposed to linalool vapor, an alcohol found in lavender [38]. Critically, this effect is not found in anosmic mice (i.e., those unable to smell), indicating that olfactory input is responsible for the anxiolytic effects of linalool [38].

### Touch

Interpersonal touch powerfully buffers people against stress and anxiety [39]. Experimental research indicates that affectionate touch reduces state anxiety among patients in critical care wards [40], people prompted to think about their death [41], and individuals under threat of an electric shock [42]. Longitudinal interventions that increase interpersonal touch between romantic partners lead to significant declines in both physiological and self-reported stress [43,44]. Beyond human touch, research shows that engaging in experiences that simulate affectionate human tactile experiences, such as petting animals [45], touching soft objects (e.g., a teddy bear) [41], feeling a weighted blanket [46], and being touched by robots [47], can significantly reduce stress and anxiety.

### Taste

Many tastes produce positive or negative emotional reactions [19,20]. Sweet, umami, and sometimes salty tastes trigger positive emotions and are linked with activations in pleasure-mediating brain regions, including the nucleus accumbens and amygdala [18,48]. In animal studies, rats who binge on sugar show an immediate release of **dopamine**, a neurotransmitter that induces feelings of pleasure [49]. Further, chocolate consumption robustly reduces negative affect in

both longitudinal randomized controlled trials [50] and laboratory experiments [51]. Conversely, bitter tastes immediately confer deleterious effects on mood and induce disgust [52].

### Sight

Visual stimuli are among the most commonly used tools to induce positive and negative emotions in the laboratory (e.g., the International Affective Picture System) [4]. Notably, viewing static nature scenes reduces stress [53] and negative affect [54], facilitates recovery from social pain [55], and induces relaxation [56]. Further, viewing pornographic images rapidly stimulates brain reward networks such as the ventral striatum to produce feelings of pleasure [57]. Visual art can also confer emotional benefits; Viewing an online art exhibition decreases loneliness, negative mood, and anxiety [58], and a brief visit to an art museum reduces self-reported stress and salivary cortisol levels [59]. In addition, displaying visual artwork of nature scenes in hospitals and mental health settings decreases anxiety and agitation in patients [60,61].

### Beyond regulating to 'feel better'

In sum, evidence across disciplines suggests that sensation can be strategically harnessed to upregulate positive and downregulate negative emotion. Yet, there are also instances in which people use sensory stimuli to achieve other regulatory goals. As just one example, consider research indicating that people strategically choose to listen to certain kinds of music to upregulate negative emotion. Tamir and colleagues found that people who were preparing to play a confrontational game, in which the goal was to kill members of a drug cartel, preferred to listen to angry-inducing music, whereas those who were preparing for a non-confrontational game (helping a waitress deliver food to customers) chose to listen to exciting or neutral music [62]. Additional research reveals that many people with depression deliberately seek sensory stimuli that exacerbate their negative affect. For example, when presented with the option to view sad or happy images, most individuals with depression choose sad images [63]. People with depression are more likely to select sad (versus happy) music than their nondepressed counterparts to maintain their negative affect and sustain their sense of self [64]. Taken together, people strategically use sensory stimuli to achieve regulatory goals beyond 'feeling better'.

### Sensation: a relatively effortless tool for emotion regulation?

Many traditionally studied emotion regulation strategies (e.g., **acceptance**, **reappraisal**, and **expressive suppression**) require mental effort; in other words, cognitive control is required to effectively implement them [65,66]. However, a growing body of work suggests that people also employ more effortless routes to emotion regulation that bypass the need for cognitive control [5,67,68]. One of the advantages of utilizing relatively effortless tools is that they increase the likelihood that people will implement them in their daily lives [68,69], as it is well-established that people shun away from exerting effort [66,69]. Although no work has directly examined the role of sensation as a relatively effortless regulatory tool, disparate sets of findings provide converging evidence that speaks to this possibility.

First, sensation affects emotion very quickly, bypassing deliberate control. For instance, interpersonal touch modulates emotion as quickly as 25 milliseconds after its onset [70], leading to almost immediate neurobiological changes, such as the release of oxytocin, dopamine, and endogenous opioids, which produce anxiolytic effects and inhibit pain [71,72]. According to neuroimaging work, hedonic properties of tastes (e.g., palatable or aversive) are processed within 100–300 milliseconds of ingestion [20,48,73], and sweet tastes immediately trigger dopamine release in the hypothalamus and insular cortex [74]. In the case of smell, the amygdala receives odorant information in as few as two synapses from the olfactory epithelium [75]. Sounds with high frequencies produce an immediate (within 30–50 milliseconds) startle fear response, a largely

unconscious and immediate reaction to threatening stimuli, in both animal and human samples [76]. In the case of sight, viewing photos of threatening animals produces a fear reflex in humans [77]. Further, fear-relevant visual stimuli take a fast, unconscious route to emotion networks in the brain, leading to peak amygdala activity within 150 milliseconds after onset [78,79].

Second, sensation activates emotional brain networks even when participants are unaware of sensory inputs. For instance, the subliminal presentation (≤50 milliseconds) of threatening faces robustly activates the amygdala and other brain regions involved in the generation of emotion (e.g., hippocampus and insular cortex) without participants' explicit awareness of viewing the images [80]. In laboratory and field settings, low-intensity odors influence self-reported emotions and activate brain areas involved in emotion even when individuals cannot detect them [81]. Strikingly, unresponsive coma patients in a minimally conscious state exhibit an intact startle reflex in response to sounds [82]. Further work is needed to investigate whether touch and taste stimuli impact emotions when under conscious awareness.

Third, sensation impacts emotions even when individuals are under cognitive load. For example, tasting a sweet drink activates the gustatory cortex and associated emotional responses even when participants are distracted [83]. In addition, amygdala activation in response to images of fearful faces persists when individuals are attending to another demanding task [84]. Petting a dog significantly reduces physiological indicators of stress (e.g., heart rate and salivary cortisol levels) during and after a cognitively taxing laboratory task [85]. Further, spontaneously touching one's face during a working memory task leads to immediate neurophysiological changes that promote emotion regulation [70]. Lastly, listening to relaxing music after a demanding performance task increases positive affect and reduces mental fatigue according to behavioral and **event-related potential** evidence [86]. By contrast, regulatory strategies that are more cognitively demanding (such as reappraisal) are less effective when people are under cognitive load; this is because cognitive load taxes the same cognitive control networks required to successfully implement these strategies [87].

Fourth, the effects of sensation on emotion are observed among infants, who have not developed the cognitive control needed to use more effortful regulatory strategies. For example, among crying newborn infants, an orally administered sucrose solution (vs. water) immediately exerts a calming effect that persists for several minutes [88]. **Electroencephalogram (EEG)** data indicate that 7-month-old infants display= markedly reduced fear responses in the presence of a threat when exposed to their mother's odor versus the odor of a different mother or no odor [89]. In addition, skin-to-skin contact consistently regulates infants' physiological stress [90], and in a gentle touch intervention for preterm infants, nurse-administered touch led to reduced distress among infants (vs. controls who did not receive touch) [91].

Taken together, various lines of evidence support that sensation constitutes a relatively effortless route to emotion regulation.

## Synthesis and moving forward

Extant research indicates that: (i) the process of sensation is inherently emotional; (ii) sensation-driven emotion can be deliberately harnessed; and (iii) sensation relatively effortlessly activates emotional processes. Together, this work suggests that sensation constitutes a tool that people can use to deliberately manage their emotions.

Despite this evidence implicating sensation as a regulatory tool, prominent emotion regulation models do not explicitly discuss this possibility. Here, we suggest that doing so has the potential to broaden our understanding of the tools people have to manage their emotions, highlighting the

role of a set of relatively effortless emotion regulatory processes that individuals have used for millennia and continue to use today. Integrating the study of sensation into emotion regulation also places us in a position to better understand both how to optimize the usage of these sensory regulatory tools and how sensory experiences interact with other regulatory strategies. It also encourages the formation of integrative, multilevel models of emotion regulation. To this end, we outline several open questions regarding the use of sensation for emotion regulation and propose directions for future research on this topic (see Outstanding questions).

### Incidental versus strategic activation

Do the effects of sensory emotion regulation tools on emotion depend on whether the sensation is incidentally or strategically activated? Consider the unexpected joy of stumbling upon the smell of freshly baked bread while walking across town [92]. How do incidental sensory experiences compare with those that are intentionally sought out (e.g., visiting the bakery to indulge in the smell of baked bread) in terms of the intensity of the emotional responses they generate?

### Duration of effects

How long do the emotional effects of sensory experiences last? Sensation often activates our emotional system automatically, but there may be significant variability in the duration of its effects. For instance, tasting a piece of chocolate only boosts mood for a few minutes [51], while listening to music can improve mood for several hours [93]. The duration of emotional effects may vary by sensory modality, the intensity of sensory activation, or the duration of the sensory experience itself [94]. Probing this question further is important to better understand how sensation can be most strategically and effectively harnessed to regulate emotions.

### When sensation is helpful versus harmful

Another crucial question for future research concerns when and why sensory experiences help or harm us. Although our review primarily focuses on the benefits of sensation on adaptive emotion regulation, there are well-documented instances in which sensory experiences lead to negative emotional outcomes. For instance, both **binge eating** and **self-injurious behaviors** temporarily relieve negative affect [95,96], but lead to adverse long-term outcomes, such as a greater risk of physical and mental health conditions [97,98]. Finally, there may be a dark side to using music to regulate emotions. People tend to select music that is congruent with their current emotional state (e.g., people who are feeling sad often listen to sad music) [99]. However, evidence indicates that listening to sad music when feeling sad maintains or amplifies sadness and amplifies **rumination** [100].

Along these lines, it is also interesting to examine whether the efficacy of sensory emotion regulation tools varies at differential levels of emotional intensity. For instance, does a comforting bowl of chicken soup help soothe mild, but not severe, stress? Given that the efficacy of other regulatory tools, such as reappraisal, depends on the intensity of the emotional state, the same may be true for sensory tools.

### Role of individual and cultural differences

A constellation of individual differences and contextual factors may shape whether sensory experiences lead to beneficial regulatory outcomes. For instance, the effects of interpersonal touch on emotion depend on personal preferences for touch [101], sensitivity to sensory input [102], and the relationship between the giver and receiver [103]. The emotional effects of touch are also shaped by cultural norms surrounding tactile behavior, including the appropriate amount of touch, forms of touch, and its acceptability and meaning [104]. These findings highlight the role that individual differences and contextual factors can have in modulating the benefits of touch

for emotion regulation. Future research is needed to examine how similar factors influence the way other sensory modalities impact emotions.

Further evidence suggests that our perceptions of sensory input are moderated by momentary emotional states. In other words, sensation not only impacts how we feel; the emotions we feel may also impact how we see, taste, and hear. For instance, socially anxious people interpret images of ambiguous faces as more threatening than people who are not socially anxious [105]; people who are thirsty perceive a water bottle to be spatially closer to them compared with nonthirsty people [106]; people who are happy taste a sample of ice cream as sweeter and more enjoyable than those who are unhappy [107]; and people high in negative affect perceive sounds as louder, more negatively valenced, and more fear-inducing [108]. Future work is needed to examine how momentary emotional experiences shape the sensory modalities of touch and smell.

### Interactions between multiple sensory channels

In this review, we highlight key findings demonstrating the impact of individual sensory modalities on emotion regulation. Yet, the senses rarely work in isolation; our daily experiences are often the products of multisensory interactions between what we see, smell, hear, touch, and taste in any given place and time [109]. Exposure to nature, which provides well-documented benefits for emotion regulation, is a prime example of a multisensory experience (Box 3). Yet, we know little about how sensory experiences work in concert.

### Interactions with other regulatory strategies

Future work is also needed to examine how sensory experiences interact with other regulatory strategies. As noted in Box 2, sensory stimuli can influence emotion indirectly by diverting

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**Box 3. Nature as a multisensory experience**

Accumulating evidence over the past two decades has revealed the salubrious effects of spending time in nature. Exposure to natural environments reduces stress and negative affect [127], buffers against mental disorders [128], and increases subjective wellbeing and positive affect [129].

Prior work has posited several mechanisms through which nature confers affective benefits, including attention replenishment, the ease of processing natural stimuli, and the presence of low-level visual features [130]. One factor that is less heavily investigated is the role of sensation in partly explaining the benefits of nature.

Engaging with nature is a multisensory experience. For instance, a walk in the park activates visual (e.g., seeing children playing), auditory (e.g., hearing birds chirping), tactile (e.g., wind hitting the body), and olfactory (e.g., smelling freshly cut grass) sensory modalities simultaneously.

Much of the work on the affective benefits of nature focuses on its visual aspects [130,131]. Yet, emerging evidence suggests that some of these affective benefits arise from nonvisual sensory stimuli [131]. For instance, natural sounds and smells activate psychophysiological pathways that promote stress reduction [132,133]. Further work is needed to examine how sensory experiences aside from visual cues may contribute to the emotional benefits of experiences in nature.

Nature exposure provides a prime case study to examine the effects of multimodal sensory experiences on emotion regulation. Recently, experimental research has leveraged virtual reality technology to immerse participants in natural environments. Such studies activate combinations of sensory modalities (e.g., visual, auditory, and olfactory) in a controlled fashion to examine their combined effects on affect [133,134]. This innovative work may shed light on the additive or interactive effects of activating combinations of sensory modalities on emotion regulation.

Beyond controlled laboratory studies, future research should examine the interplay of sensory experiences in the real world. Given that racial minorities and low-income individuals have less access to nature in the US [135], the benefits of nature exposure may not be received equitably. Further, impoverished neighborhoods with concentrated levels of poverty may expose residents to an array of adverse sensory experiences that negatively impact wellbeing (e.g., urban noise pollution, neighborhood disorder, and greater access to alcohol and harmful substances). Thus, residents of impoverished areas may suffer from both an absence of positive sensory experiences and the ubiquity of negative sensory experiences.

attention from unpleasant emotions, helping people reframe negative experiences, and activating autobiographical memories that trigger emotional experiences. This highlights the need to understand not only how sensation operates to regulate emotions directly, but also how it interacts with other processes to regulate emotions. If sensory emotion regulation tools do not target underlying cognitive representations that fuel stress and anxiety, they may not have long-term effects [110]. However, sensory experiences may facilitate the use of other regulatory tools (e.g., reappraisal or acceptance) because they rapidly lift mood and free up cognitive resources to implement more effortful strategies [111]. Thus, attentional or cognitive regulatory strategies may constitute a mechanism through which sensation confers regulatory benefits.

## Translational research

From a translational perspective, work is needed to test evidence-based interventions that leverage sensory processes to improve wellbeing. Sensory interventions may be especially useful for clinical populations because they are easy to implement and have immediate effects on emotion. For instance, the neuroanatomical links between emotion and olfaction have given rise to novel therapeutic techniques for psychiatric disorders [112]. Olfactory Virtual Reality decreases anxiety, stress, and pain among psychiatric inpatients with a range of conditions (e.g., depression, bipolar disorder, post-traumatic stress disorder, and anxiety disorders) [113]. Another potential avenue for future research along these lines involves implementing sensory interventions at the community level. For example, future work may consider designing pleasant ambient sensations in public spaces and testing their effects on residents' wellbeing [114].

## Concluding remarks

Throughout history, humans have leveraged the senses to modify which emotions they feel, their intensity, and their duration. Over the past two decades, research has made great strides in advancing our understanding of emotion regulation. Here, we seek to enrich contemporary thinking on this topic by highlighting sensation as a potentially effortless and effective gateway to emotion regulation. To this end, we integrate knowledge from diverse disciplines and across levels of analysis. Several questions remain, and this theoretical integration opens new avenues for basic science and applied work. We encourage future research to elucidate how, for whom, and in what contexts activating sensory modalities can maximally benefit emotional wellbeing.

### Declaration of interests

No interests are declared.

## Outstanding questions

Do the emotion-regulatory effects of sensory experiences depend on whether sensation is incidentally or strategically activated?

What is the duration of the emotion-regulatory effects of sensory experiences and how does duration vary by sensory modality?

When does sensory emotion regulation help versus harm us? When do sensory experiences lead to functional versus dysfunctional emotion regulation?

Which individual differences, cultural, and situational factors are most important in shaping the effects of sensory tools? Past research suggests that emotion regulation strategies lead to different outcomes in different contexts and for different people. Is the same true for sensory experiences?

How does utilizing multiple sensory tools in combination (e.g., smell and sound) impact emotional outcomes? Are the effects of cross-modal sensory tools on emotion additive or interactive?

How do sensory emotion regulation tools work in concert with other types of regulatory strategies (e.g., reappraisal, acceptance, or expressive suppression)? Does activating sensory emotion regulation tools facilitate or undermine an individual's ability to use other regulatory tools?

How does activating sensory emotion regulation tools in urban or public spaces impact residents' wellbeing?

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