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REVIEW ARTICLE

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Sensory stimulation via the visual, auditory, olfactory and gustatory systems can modulate mood and depression

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Abstract

Depression is one of the most common mental disorders, predicted to be the leading cause of disease burden by the next decade. There is great deal of emphasis on the central origin and potential therapeutics of depression whereby the symptomatology of depression has been interpreted and treated as brain generated dysfunctions filtering down to the periphery. This top-down approach has found strong support from clinical work and basic neuroscientific research. Nevertheless, despite great advances in our knowledge of the aetiology and therapeutics of depression, success in treatment is still by no means assured. As a consequence, a wide net has been cast by both clinicians and researchers in search of more efficient therapies for mood disorders. As a complementary view, the present integrative review advocates approaching mood and depression from the opposite perspective: a bottom-up view that starts from the periphery. Specifically, evidence is provided to show that sensory stimulation via the visual, auditory, olfactory, and gustatory systems can modulate depression. The review shows how—depending on several parameters—unisensory stimulation via these modalities can ameliorate or aggravate depressive symptoms. Moreover, the review emphasises the bidirectional relationship between sensory stimulation and depression. Just as peripheral stimulation can modulate depression, depression in turn affects—and in most cases impairs—sensory reception. Furthermore, the review suggests that combined use of multisensory stimulation may have synergistic ameliorative effects on depressive symptoms over and above what has so far been documented for unisensory stimulation.

KEYWORDS
affect, bottom-up model, mood, multisensory stimulation, top-down model

1 | INTRODUCTION

Depression is one of the most common mental disorders and is predicted to be the leading cause of disease burden by 2030 (Kessler, 2012; Malhi, 2018; World Health Organization, 2012, 2017). While clinicians and researchers in the field have greatly advanced our knowledge of the aetiology of depression and provided new therapeutic methods, success in treatment is still by no means assured (Akil et al., 2018; Blackburn, 2019;

Johnston et al., 2019; Trivedi et al., 2006). As a consequence, a wide net has been cast by both clinicians and researchers in search of more efficient therapies for mood disorders. To this end, clinical work and basic research have targeted the central mechanisms that underline the aetiology of depression and provided the basis for medical treatment. Thus, there has been a great deal of emphasis on the central origin and potential therapeutics of depression. The symptomatology of depression ranging from psychomotor retardation and anhedonia to cognitive impairment consequent to the emergence of the psychopathology have been interpreted as centrally generated dysfunctions filtering down to the periphery. This top-down approach has found overwhelming support from clinical work benefitting among others from pharmacotherapy (Krishnan & Nestler, 2010; Matveychuk et al., 2020; Murrough & Charney, 2012; Sanacora et al., 2012), various invasive and noninvasive centrally applied electrical/magnetic stimulation techniques (Andrade et al., 2010; Askalsky & Iosifescu, 2019; O'Reardon et al. 2007; Qi et al., 2020; Sackeim, 2000; Singh et al., 2020) as well as deep brain (Dandekar et al., 2018; Kisely et al., 2018) and vagal stimulation (Carreno & Frazer, 2017; Conway & Xiong, 2018; George et al., 2002).

Thus, the field of depression therapy and research has been solidly based for several decades on a central approach. Alongside this central approach, there is a complementary view that approaches mood and depression from the opposite perspective: a peripheral, bottom-up view that starts from the periphery and moves up centrally to integrate with the major central structures and functions that have been implicated in the aetiology of depression. Two review articles in the last decade (Canbeyli, 2010, 2013) advanced the complementary view that stimulation via the unisensory modalities such as vision or audition as well as physical exercise has the power to alleviate or aggravate depressive symptoms depending on several parameters such intensity, frequency, duration and quality of stimulation. The papers marshalled ample evidence to suggest that a bottom-up approach to depression not only should figure in the therapeutics of depression but may also provide clues to its pathogenesis. Approximately a decade after the original review, there is a plethora of new supportive evidence that expands the scope of the bottom-up view to emphasise the relevance of the bottom-up approach for a comprehensive evaluation of depression.

Before considering the potential merits of the bottom-up approach proposed earlier in the two review papers and espoused in the present paper as essential part and parcel of depression research, the reasons for the overwhelming current emphasis on the central view of the pathology must be addressed. First and foremost, depression is mainly if not exclusively a human affliction that requires urgent action since it is now considered to be a worldwide health threat. Second, even though research on animal models of depression has provided valuable insights into depression (Krishnan & Nestler, 2011; Czéh et al., 2016; Ménard et al., 2016; Hao et al., 2019; Unal & Canbeyli, 2019), depression is basically a major human health burden at the individual and societal levels (WHO, 2016, 2018; GBD 2018; Malhi, 2018). Lastly, vast progress over several decades in the neurochemistry, neurophysiology and neuroanatomy of depression involving humans as well as animal models seems to justify an exclusively central, top-down approach. Thus, depression is overwhelmingly considered as a dysfunction in the neurophysiology and neurochemistry of a fronto-limbic circuitry components of which are not only more numerous now than just a few decades ago but also considerably better understood thanks to advances in neuroimaging, as well as therapeutic superficial and deep brain stimulation techniques (Duman et al., 2019; Jones & Nemeroff, 2021; Kisely et al., 2018; Nugent et al., 2019).

The present review does not by any means advocate a dichotomic provenance, namely, central versus peripheral source of depression but will emphasise the essential relevance of the peripheral inputs to the central mechanisms involved in the pathogenesis of and the potential therapeutic tools for depression. To appreciate the importance of peripheral stimulation in modulating depression, the paradoxical status of the brain as a priviledged organ of the body must be taken into account; thanks to the skull, the meninges, cerebrospinal fluid and the brain-blood barrier, the brain is the most protected organ against internal and environmental threats and physicochemical fluctuations, while at the same time it is also the most receptive to physical and sensory input from the periphery. Contrasting with these elaborate protective systems is the reality that the brain unlike most internal organs provides access to physicochemical inputs, particularly via the sensory sytstems of vision, audition, olfaction and gustation with the last two systems directly allowing bodily access to physicochemical stimuli in the form of smells and ingested foods and drinks. Importantly, the review not only documents the mood modulatory effects of sensory stimulation via the visual, auditory, olfactory and gustatory systems but also emphasises the growing evidence that such unisensory stimulation has the potential to alter—and often impair—the central substrates involved in mood and depression. This in turn results in modified central sensory reception further complicating the interaction between the peripheral and central processing of sensory stimulation.

The subsequent sections of the review will deal with new insights into the potential contribution of peripheral stimulation to mood modulation considering two important points in sensory reception. First, it will be shown that individual differences in sensory reception may contribute to variability in the mood modulatory effects of peripheral stimulation. Second, the review will also argue that instead of unisensory stimulation via one of the sensory systems, multisensory stimulation involving combinations of these modalities may lead to an enhanced ameliorative effect on depression. Due to limitations of space, the review will deal mainly with evidence from human studies.

2 | VISION

In addition to seeing, the visual system starting at the retinal level has also non-image forming functions that are still under investigation. One major aspect of these functions is the modulation of emotion and mood. Studies indicate that the intensity, duration, timing and spectral quality of light significantly affect the impact of the visual system on emotion and depression (Jean-Louis et al., 2005; Vandewalle et al., 2010).

2.1 | Light improves mood and alleviates depressive symptoms

Modulation of mood by light is a globally experienced phenomenon as shown by the contrast in how people generally feel during the short and long days of winter and summer, respectively. Compared with the other sensory systems to be discussed below, the ameliorative effects of light stimulation have been studied more thoroughly and utilised more effectively for clinical purposes in the form of phototherapy. Starting in early 1980s, exposure to bright light for approximately 1 h early in the morning or evening has been shown to alleviate depressive symptoms in patients suffering from seasonal (Lewy et al., 1982; Avery, 1998; Oren & Terman, 1988; Pjrek et al., 2020) and non-seasonal depression (Even et al., 2008; Kripke, 1998; Mackert et al., 1991; Pail et al., 2011).

In addition to its use in controlled clinical practice, bright light stimulation has beneficial effects on depressive symptoms in uncontrolled or non-clinical environments. Thus, inadvertent exposure to bright light in the form of staying in sunny hospital rooms has been reported to significantly shorten duration of hospitalisation for depressed patients compared with those in ‘dull’ rooms (Beauchemin & Hays, 1996). Exposure to artificial bright light can also have ameliorative effect on mood in nonclinical populations. Repeated exposure in the winter to at least 1 h of light reduced depressive symptoms in healthy office workers with or without winter-related mood symptoms (Partonen & Lönnqvist, 2000). Similarly, combining bright light exposure with exercise over an 8-week period significantly reduced depressive symptoms in healthy adults compared with exercise in normal indoor illumination (Leppämäki et al., 2002).

In addition to being used as monotherapy, bright light stimulation is also utilised as an augmentation of pharmacotherapy (Al-Karawi & Jubair, 2016; Guzel Ozdemir et al., 2015; Niederhofer & Von Klitzing, 2012). A review of studies using bright light treatment along with various pharmacotherapies indicated that phototherapy improved treatment of major depression compared with pharmacotherapy alone (Penders et al., 2016).

2.2 | Inadequate light photoreception or visual dysfunction can aggravate mood and depressive symptoms

Just as bright light stimulation is conducive to good mood and can ameliorate depressive symptoms, inadequate photoreception due to low or shortened periods of illumination as in the winter months is a globally experienced source of lowered mood and exacerbated depressive symptoms. This is not just valid for those who suffer from seasonal affective disorder (SAD), a subtype of depression characterised by increased depressive symptoms in the fall and winter with remission in the summer, but also for people who live in areas receiving little sunlight throughout the year (Booker et al., 1991). Since studies attest to the depressogenic effects of low or inadequate photoreception (Espiritu et al., 1994; Jean-Louis et al., 2005; Park et al., 2007), depressive symptoms should be expected to be frequently observed in people with visual impairments that limit the level of experienced illumination. This is indeed the case as confirmed by clinical reports of significantly increased incidents of depression in people with ophthalmic dysfunctions involving lowered photoreception and/or reduced visual acuity (Rovner et al., 2002; Rovner & Shmuely-Dulitzki, 1997; Shmuely-Dulitzki & Rovner, 1997).

2.3 | Depression can modulate visual processing and photoreception

The centrifugal/top-down relation between depression and vision involves modification—in most cases impairment (Bubl et al., 2010; but see Golomb et al., 2009)—by depression of visual processes starting at the retina reaching up to subcortical and cortical levels. Depressed patients are challenged in visuospatial tasks (Asthana et al., 1998), and the visual system is sensitive to manipulations of mood and to depressive symptoms as shown by alterations in visual perception of faces according to different emotional states induced by music (Lolij & Meurs, 2011). High trait anxiety interacting with presentation of fearful faces exacerbates visual contrast sensitivity (Ferneyhough et al., 2013). In fact, impaired perception of emotion in depression may be a stable deficit (Kohler et al., 2011; Leppänen et al., 2004; Muller et al., 2014).

In addition to the modulation of visual attention involving specific features, particularly facial ones, affect can modulate the scope of visual processing as shown by the report that induced sad or happy moods promote local versus global visual features in a drawing task from memory (Gasper & Clore, 2002). Furthermore, affective states can bias gaze and visual attention to salient visual features (Vuilleumier, 2015).

Several studies emphasise the fact that perceptual deficits in visual processing in depression are not limited to emotional and affective states but point to a more profound impairment in the functioning of the visual system starting at the retinal level. Depression is reported to result in dysregulation of visual motion inhibition as measured by performance on motion detection with a center-surround suppression task (Norton et al., 2016). Similarly, Desseilles et al. (2009) found in an fMRI study that patients with major depressive disorder had difficulty detecting nonemotional stimuli (presented at a fixed central visual location) because of abnormal filtering of irrelevant stimuli presented in the periphery.

Modulation of visual processing by affective states or depression starts at the retina and continues at subcortical and cortical structures. (Cosker et al., 2020). Using electroretinogram (ERG) to measure retinal function, Lavoie et al. (2009) found significantly lower cone ERG in patients suffering from SAD. Compared with controls sensitivity to blue light as measured with pupillary light reflex is increased in depressed patients and is reduced after antidepressant treatment (Seggie et al., 1989).

Neuroimaging studies reveal that emotions and depression can modulate central processing of visual input (Adolphs, 2004; Bar & Neta, 2007;195 Meier et al., 2007). For example, an fMRI study with depressed patients showed differential asymmetric activation of several limbic structures that were correlated with severity of depression (Lee et al., 2007). Another study using color and slides with emotional images found that compared with healthy controls depressed patients displayed reduced responses in late stages of visual processing as measured with event-related potentials (ERPs) which recovered after pharmacotherapy (Pause et al., 2003).

3 | AUDITION

For humans, auditory stimulation, particularly music, is not only an effective but also very likely the oldest means of modulating emotions and mood as it has been practiced universally in the last several thousand years (Heise et al., 2013; Nizamie & Tikka, 2014; Rollin, 1998). However, both the methodical applications and neuroscientific investigations of the mood modulatory aspects of different auditory stimulation, particularly musical treatment, are relatively recent (Aalbers et al., 2017; Abbott, 2002; Croom, 2012; Kemper & Danhauer, 2005; Sachs et al., 2015). There is now strong evidence for the bidirectional–reciprocal relationship between hearing and mood and depressive disorders; a variety of auditory stimulation can modulate mood and depressive symptoms, while depression has the capability to alter auditory perception.

3.1 | Auditory stimulation can modulate mood and alleviate depression

A large range of auditory exposure varying from musical compositions to a variety of non-musical stimulation can modulate mood (Albersnagel, 1988; Clark, 1983; Gagner-Tjellesen et al., 2001). While auditory stimulation has been shown to alleviate depressive or anxious mood (Bouhuys et al., 1995; Hsu & Lai, 2004; Pignatiello et al., 1986; Smith & Noon, 1998; Thompson et al., 2001; Tornek et al., 2003), acute or chronic exposure to noise has negative psychological consequences (Gomez & Danuser, 2004; Stansfield, 1992). There is a paucity of systematic studies on the effects of noise on depression in humans. Nevertheless, a large-scale study in Amsterdam assessed depressed mood by means of the nine-scale Patient Health Questionnaire over approximately 5 years with a large number of subjects living in various locations with different levels of ambient traffic noise. Results indicated a significant positive association with depressed mood for those exposed to noise levels greater than 70 dB compared with the reference group who experienced 45- to 54-dB exposure (Leijssen et al., 2019).

Mood modulatory nature of auditory stimulation is not limited to musical compositions. For instance, stimulation with musically enhanced birdsong early in the morning induces positive mood and decreases depression as measured by Beck Depression Inventory (BDI) and

Profile of Mood States (Goel & Etwaroo, 2006; Goel & Grasso, 2004). Similarly, inducing binaural auditory beats by presenting tones of slightly different frequency to the two ears so as to create EEG activity in the delta/theta (1.5 to 4 Hz) range has been shown to result in negative mood compared with induction of activity in the beta wave range of 16 to 24 H (Lane et al., 1998).

Recent years have seen an increased interest in and use of music therapy for depression either as a low-cost monotherapy (Kemper & Danhauer, 2005; Lin et al., 2011) or as augmentation or enhancement to established standard psychotherapies (Erkkilä et al., 2011; Gold et al., 2009; Zhao et al., 2016). Minimal negative side effects, practical applicability tailored not just to individuals but to groups, combined with cost efficiency make it very likely that music therapies will figure more prominently in treatment of depression in the future, particularly with more systematic studies of the optimal parameters (Choi et al., 2008; Hillecke et al., 2005; Leubner & Hinterberger, 2017).

3.2 | Impaired audition can aggravate mood and induce depression

Some types of auditory stimulation and music can lower mood and induce depressive symptoms (Abbott, 2002; Kemper & Danhauer, 2005; Pignatiello et al., 1986; Smith & Noon, 1998; Thompson et al., 2001). On the other hand, compromised hearing resulting in limited auditory reception can also result in negative mood and increased depressive symtoms. For instance, not only total deafness but also compromised audioreception due to hearing impairment result in increased rates of depressive symptoms (Blazer & Tucci, 2019; Leigh et al., 1989; Leigh & Anthony-Tolbert, 2001; Magilvy, 1985; Steinberg et al., 1998; Watt & Davis, 1991; Zazove et al., 2006). Moreover, tinnitus, a hearing disorder involving perception of sound without an external source, is significantly correlated with depression (Stephens & Halam, 1985; Sullivan et al., 1988; Budd & Pugh, 1995; Langguth et al., 2011). Interestingly, a large-scale Korean study based on self-reported hearing impairment showed that individuals with hearing loss had significantly more depressive symptoms than those who had good hearing (Han et al., 2019).

3.3 | Low mood or depression can affect auditory function

Emotion and affective states can influence auditory perception at various levels of processing (Erhan et al., 1998; Brandao et al., 2001). Perception of auditory loudness occurs early in the auditory processing hierarchy; Wang et al. (2009), for instance, reported that negative affect can modulate the central auditory response to speech within 20 ms. Pollock et al. (2006) demonstrated that subjects with high anxiety sensitivity had lower thresholds for reception of heartbeat. Compared with controls, auditory tones are rated as louder by subjects with negative affect (Siegel & Stefanucci, 2011) and thresholds for pure tones are decreased in depressed subjects with traumatic disorder (Aubert-Khalfa et al., 2010).

Several lines of research indicate that depression alters auditory perception at various stages of processing (Doose-Grünefeld et al., 2015). Depression impairs the evaluation of affective prosody (Schlipf et al., 2013; Uekermann et al., 2008) and music (Naranjo et al., 2011). Another study reported that compared with controls, depression did not alter the pleasure derived from a pleasant pure tone, but significantly reduced the pleasure from the repetition of the tone (Collet & Duclaux, 1986).

In addition to findings that locate the impairment of auditory reception in depression at early stages of processing, there are studies that indicate cortical involvement in the negative effect of depression on auditory function. An fMRI (Michael et al., 2004) and a magnetocephalography (Tollkötter et al., 2006) study showed that depression can alter habituation in the auditory cortex to repeated presentation of sine tones. Hearing loss and auditory perceptual asymmetry are also reported in depression (Bruder et al., 1975; Malone & Hemsley, 1977). Several studies with depressed patients report a reduction of the left ear (right hemisphere) advantage for nonverbal tasks compared with nondepressed subjects (Bruder et al., 1981; Johnson & Crockett, 1982; Overby et al., 1989). Similarly, assessment of auditory sensitivity by means of pure tone and click audiometry in depressed patients indicated bilateral hearing loss and auditory asymmetry in the form of poorer hearing in the left ear (Yovell et al., 1995).

4 | OLFACTION

Olfaction is evolutionarily the oldest sensory system providing vital cues to humans and animals as they navigate in their natural environment. That odour that can modulate emotions is a universal phenomenon and an idea not lost to producers of expensive perfumes. More importantly, several decades of research have shown that depending on several parameters including quality, intensity and duration odours can modulate mood and depression (Kadohisa, 2013; Komori et al., 1995; Kontaris et al., 2020; Rochet et al., 2018; Schiffman et al., 2000).

4.1 | Olfactory stimulation improves mood and alleviates depressive symptoms

Several studies with nonclinical subjects indicate modulation of mood and depressive symptoms by pleasant and unpleasant odourants. For understandable reasons there are only a few studies that have assessed the deleterious effects of malodourous smells on mood and depression. Nevertheless, two studies using unpleasant odours akin to smell of rotten eggs, sodium sulfide (Weber & Heuberger, 2008) and dimethyl sulfide (Knasko, 1992) reported negative effects on mood while vanillin, a pleasant odour had the opposite effect. Conversely, several studies report elevated mood as a result of exposure not only to natural pleasant odourants such as lemon oil (Kiecolt-Glaser et al., 2008), lavender fragrance (Field et al., 2005; Goel & Grasso, 2004), Japanese cedar wood odour (Matsubara & Ohira, 2018) and citrus fragrance (Komori et al., 1995) but also to a synthesised odour derived from glycine/glucose Maillard reaction (Zhou et al., 2016). While most studies that have demonstrated ameliorative effects of odours were conducted in experimental environments, others indicate that mood can be improved by ambient odour stimulation in a natural outdoor setting (Glass & Heuberger, 2016) or in a dental office (Lehrner et al., 2000, 2005).

4.2 | Depression can modulate olfactory processing

Just as odours modulate mood and depressive symptoms, depression in turn can alter olfactory processing and sensitivity to odours (Flohr et al., 2017; Hoenen et al., 2017; Hur et al., 2018; Pollatos et al., 2007; Qazi et al., 2020). For instance, a study showed that depressed patients who were comparable with controls in the olfactory task before antidepressant treatment significantly increased their sensitivity to iso-amyl acetate 6 weeks after treatment onset (Gross-Isseroff et al., 1994). Pause et al. (2001) reported a reduction in olfactory sensitivity in depression proportional to the severity of the symptoms which was subsequently alleviated by antidepressant treatment. Similarly, a negative correlation was observed between sensitivity to odourants and the level of depression in healthy subjects as measured by BDI (Pollatos et al., 2007]. One important aspect of this top-down influence on olfaction is the fact that the emotional and olfactory systems are intricately related with shared neuroanatomical structures (Laudien et al., 2006; Savic, 2001; Zald & Pardo, 1997, 2000). This is dramatically evident in reduced volume of olfactory bulb in major depressive disorders resulting in impaired olfactory function (Negoias et al., 2010). In fact, changes in the olfactory bulb volume and olfactory dysfunction have been proposed as potential biomarkers for depression (Atanasova et al., 2008; Brand & Schaal, 2017; Croy et al., 2014; Croy & Hummel, 2017; Rottstaedt et al., 2018). A psychophysiological study (Pause et al., 2003) assessed central processing of olfactory cues by means of chemosensory ERPs (CSERPs) in patients with major depressive disorder to a pleasant and an unpleasant odour. Results indicated impairment in the early level of olfactory stimulus processing compared with healthy controls. Similarly, CSERP recordings in healthy subjects revealed impairment in early aspect of olfactory processing when transient learned helplessness was induced by means of an unsolvable social discrimination test (Laudien et al., 2006).

Despite strong evidence for modified central olfactory system, there is no consensus as to the impact of depression on the peripheral effects of odourants in depressed patients with considerable inconsistencies in the reporting. For example, olfactory sensitivity is reported as unaltered in non-seasonal depression (Amsterdam et al., 1987; McCaffrey et al., 2000) and either unaltered (Oren et al., 1995) or increased (Postolache et al., 2002) in seasonal depression. Nevertheless, in addition to odour identification impairment (Khil et al., 2016), several studies have found a reduced sensitivity to pure olfactory (rather than trigeminal) cues in depressed patients with relatively severe symptoms (Lombion-Pouthier et al., 2006; Serby et al., 1990). Pause et al. (2001) reported a reduction in olfactory sensitivity in depression proportional to the severity of the symptoms which was subsequently alleviated by antidepressant treatment.

Factors that may contribute to the disparity in these reports arise from the fact that olfactory dysfunction may present itself as altered thresholds for and changes in sensitivity or emotional responses to odourants (Kohli et al., 2016). Differences in the medication status as well as duration of depression may also contribute to the inconsistent findings (Pabel et al., 2018). Nevertheless, according to two recent systematic reviews (Kohli et al., 2016; Taalman et al., 2017), a majority of studies reveal olfactory dysfunction in depression.

5 | GUSTATION

Unlike the other sensory systems taken up above which are usually subject throughout the day to varying degrees of ambient stimulation not all of which are voluntarily sought and willingly accepted, gustatory stimulation is usually individually initiated and punctate in nature in the form of meals and snacks. Moreover, more so than the other sensory systems taken up earlier, gustatory cues are often bimodal in character, olfactory cues accompanying and modulating the impact of foods. Additionally, food items and eating habits are more closely determined by cultural norms and availability of foodstuffs dependent at least partially on geographical location and seasonal variability. Despite all these complications, there is a great deal of evidence for a bidirectional interaction between food intake and affect in that what we eat can modulate mood and depression, which in turn can impact our eating habits. What makes this bidirectional interaction difficult to delineate precisely at this stage but a worthy scientific challenge is the fact that the process of gustation from chewing to digestion directly involves more bodily systems including the gastrointestinal tract and the brain than the other sensory modalities (Breit et al., 2018; Ekstrand et al., 2017; Lach et al., 2018; Morkl et al., 2018; Vincis & Fontanini, 2019; Winter et al., 2018; Yang et al., 2020; Zheng et al., 2016).

5.1 | Foods can modulate mood and depression

Studies indicate that eating a chocolate bar or an apple can elevate mood compared with eating nothing in healthy female subjects (Macht & Dettmer, 2006). Similarly, palatable but not unpalatable chocolate briefly improves negative mood induced by a film clip (Macht & Mueller, 2007). The mood modulatory effect of chocolate goes beyond its transient mood ameliorative effect after a single episode of limited consumption (Meier et al., 2017) to protracted antidepressant effect when chocolate is consumed regularly over a prolonged period of time (Jackson et al., 2019). On the other hand, chocolate consumption as a result of emotional eating in stressful conditions may prolong dysphoric mood (Parker et al., 2006).

Eating habits and dietary patterns have impact on depression that go beyond the mostly transient effects due to a single meal or snack. The impact of food on depression is more dramatically evident when people adhere to certain types of diets and eating habits over a number of years. Surveys of large number of participants numbering in many cases in tens of thousands (Liu et al., 2016; Molendijk et al., 2018), who follow different dietary regimes (Rahe et al., 2014), over many years (Adjibade et al., 2018; Le Port et al., 2012) in different regions of the world (Akbaraly et al., 2009; Li et al., 2017; Sanchez-Villegas et al., 2018; Wolniczak et al., 2017) have provided insights into both positive and negative consequences of eating habits on depression. While these surveys are mostly descriptive and correlational in nature without strict monitoring of adherence to the diets in question, they have provided valuable clues as to the general nature of foods that promote positive mood and prevent depression as opposed to those that have the opposite consequences. The overall picture that emerges from these surveys is that in general a Mediterrenean type of diet—including fruits, vegetables and olive oil—is likelier to prevent depression and promote positive mood than a diet heavy on meats, processed foods and saturated fat. In fact, studies indicate that diets rich in fruits, vegetables and fish over number of years result in lower incidence of depression than diets with absence or shortage of these food items. Interestingly, soft drinks with added sugar or diets high in sugar content are more likely to induce depression, while coffee, tea and coocoa have the opposite effect (García-Blanco et al., 2017; Guo et al., 2014; Knuppel et al., 2017; Rothenberg & Zhang, 2019; Sanchez-Villegas et al., 2018; Vermeulen et al., 2017).

5.2 | Mood and depression modulate food intake and eating habits

The bidirectional interaction between gustation and depression is evident in a large number of studies that have discovered altered food intake and gustatory preferences in depression. Dulled or altered sensations of taste can accompany depression (Hur et al., 2018; Steiner et al., 1969, 1993), partially due to fact that most antidepressants modulate monoamine function that can distort or attenuate taste perception (Ackerman & Kasbekar, 1997; Heath et al., 2006; Schiffman, 1983; Schiffman et al., 1999). Nevertheless depressed patients report an 'unpleasant taste' regardless of previous antidepressant treatment (Miller & Naylor, 1989). Moreover, oral perception of fat and taste stimuli is modulated even in healthy subjects when a depressive mood is induced by video clips (Platte et al., 2013). On the other hand, dysphoric mood and depression can lead to be strong craving for food in general (Hill et al., 1991, Hill & Heaton-Brown, 1994) or more specifically for sweet tasting foods (Christensen, 1997; Kampov-Polevoy et al., 2006). Predilection for sweet foods and refined sugars is also reported in a non-clinical population with high scores on the BDI scale (Grases et al., 2019).

Depression is also often accompanied by craving for sweet foods, carbohydrates and chocolate, particularly when individuals engage in emotional eating (Camilleri et al., 2014; Ouwens et al., 2009; Rose et al., 2010). In SAD craving for sweets and carbohydrates shows a similar pattern, increasing during the winter and decreasing in the summer (Krauchi & Wirz-Justice, 1988), while the opposite pattern is observed for sensitivity to sweet taste (Arbisi et al., 1996). Longitudinal surveys investigating the consequences of different diet patterns on depression have also discovered that depression in turn may have prolonged altered effects on gustatory preferences. Thus, a study classifying participants as depressed or not on the basis of BDI scores indicated lower consumption of legumes and fruits accompanied higher consumption of sweet foods and refined sugar in depressed than the non-depressed group (Grases et al., 2019). Adherence to unhealthy eating patterns can not only induce depression over time but also the consequent depressive state can cause people to persist in unhealthy eating regimes (Le Port et al., 2012; Wolniczak et al., 2017).

5.3 | Gut microbiota can modulate mood and depression

An important mood modulatory mechanism built into the gustatory/digestive system is the contribution of gut microbiota to maintenance of proper mental health, a phenomenon that has become a focus of research on depression relatively recently. In essence, what we eat affects the gut microbiota consisting of microbial organisms in the form of bacteria, viruses and archaea (Kelly et al., 2016; Lozupone et al., 2012; Osadchiy et al., 2020). What we eat modifies the gut microbiota, which in turn interact with the brain in a bidirectional manner neurally and hormonally (Dinan & Cryan, 2013; Mohammadi et al., 2015) The CNS modulates the composition and functioning of the microbiota neurally via autonomic regulation of the gastrointestinal system and hormonally (Cryan & Dinan, 2012; Dinan & Cryan, 2013, 2017; Osadchiy et al., 2020).

Recent studies suggest that the bidirectional nature of the gut–brain interaction is critical in modulation of mood. There is growing evidence that the gut microbiota show differences between healthy and depressed individuals. Clinical studies indicate altered microbiota in depressed patients (Jiang et al., 2015; Naseribafrouei et al., 2014), while increased incidence of depression or mood has been reported in populations exposed to microbiota altering bacterial infection (Garg et al., 2006; Lowe et al., 2014). In an interesting study, faecal microbiota from depressed and control subjects transplanted to microbiota deficient rats showed that microbiota from depressed but not control subjects induced depression-like behaviour in the recipients in the form of anhedonia and anxiety-like behaviour (Kelly et al., 2016).

5.4 | Differences in sensory reception is a factor in individual variability in depression

There is a great deal of individual variability not only in vulnerability to depression under similar depressogenic conditions but also in responding to similar therapeutic interventions. Factors leading to such variability are themselves important targets of research which is at present almost exclusively based on the central top-down account of depression. Thus, variability in outcomes can be accounted for among others by individual differences in susceptibility to stress (McEwen et al., 2015; de Kloet et al., 2016; Strain, 2018), psychobiological factors (Danion et al., 1996; Disner et al., 2011; Gonda et al., 2015; Grahek et al., 2019; Haglund et al., 2007; Pulcu & Elliott, 2015), neurobiological functions (Chaudry et al., 2015; Duman et al., 2019; Han & Nestler, 2017; Pitsillou et al., 2020; Villas Boas et al., 2019) and genetic/epigenetic factors (Freeborough & Kimpton, 2011; Klengel & Binder, 2013; Penner-Goeke & Binder, 2019; Ramos et al., 2016). While all these factors have been shown to contribute to the variability of the severity and duration of depressive symptomatology, there is now evidence to also consider differences in sensory reception as possible source of variability in depression.

The premise of the bottom-up sensorimotor hypothesis of depression is that sensory stimulation can modulate mood and depression. Most evidence to support the hypothesis is based on stimulation provided artificially in experimental or clinical settings. It is also important to consider the reverse side of the coin to assess the potential consequences of individual variability in sensory perception on mood and depression. Humans and animals can differ—in some cases widely—in their receptivity to and perception of sensory stimulation emanating from the environment (Acevedo et al., 2014; Aron et al., 2012). Thus, individuals can be hyposensitive or hypersensitive to sensory stimulation that may contribute to differences in emotional reactivity (Aron & Aron, 1997). While the full implication of super sensory sensitivity is still under investigation, there is evidence that differential sensory reactivity as evinced in hypersensitive as well as hyposensitivity (Acevedo et al., 2014) modulates emotional and affective assessment of sensory input from the environment (Lionetti et al., 2018). In the light of bottom-up approach to depression espoused in the present review, it is important to investigate the potential contribution of hyposensory and hypersensory sensitivity to mood and depressive symptomatology. In fact, a study that investigated sensory sensitivity in a large number of female and male undergraduates students (with two samples totaling more than one thousand subjects) found that the subjects could be categorised as low, middle and high sensitive groups that differed in their emotional reactivity as induced experimentally by sad and happy video clips (Lionetti et al., 2018). Given the evidence provided so far, variations in sensitivity should differentially affect emotion, mood and depression. While there is as yet a paucity of research along these lines, likely due to the recency of research interest in the topic, Serafini et al. (2017) have already shown that higher sensory sensitivity and sensory avoidance are both correlated with depression. Moreover, patients suffering from seasonal depression are more likely to score high on tests assessing super sensory sensitivity (Hjordt & Stenbaek, 2019).

Another factor that must be considered in fully assessing individual variability in the impact of sensory stimulation on mood and depression is that some individuals are particulary adverse to environmental stimulation. In extreme cases such individuals who are avoidant of sensory stimulation are considered to suffer from an as yet not clearly understood phenomenon known as sensory processing disorder (SPD). First, proposed by Ayres (Ayres, 1966, 1969), SPD at first blush seems mainly as a poorly understood developmental regulatory dysfunction afflicting children. It is characterised by sensory intolerance involving hyposensitivity or hypersensitivity to non-aversive stimuli and inability to utilise sensory information in adaptive behaviour to different situational demands. As is hypothesised by the present review, SPD is related to emotional reactivity and mood disorders (Carter et al., 2011; Engel-Yeger & Dunn, 2011, Engel-Yeger, Gonda, et al., 2016, Engel-Yeger, Muzio, et al., 2016; Liss et al., 2005; Miller et al., 2009). There is evidence that the disorder is not strictly restricted to early developmental stages as it can be exhibited by adults as well (McMahon et al., 2019). In fact, a study with a large sample of female and male English adults ($n = 6147$) showed that increased sensory impairment in hearing, vision and taste linearly increased the risk of depressive symptoms (Liljas et al., 2020). Moreover, a large literature survey indicates that major depression involves sensory alterations and may be partially due to sensory perceptual disorder (Fitzgerald, 2013).

6 | ENDING ON A POSITIVE NOTE: MULTISENSORY STIMULATION MAY BE MORE EFFECTIVE IN ALLEVIATING DEPRESSION

In real life living organisms rarely encounter pure sensory stimulation in any single modality. Natural environment almost always presents itself in the form of combination of sense data from several sensory modalities that allow humans and animals to perceive entities and situations for appropriate assessment and action. A lion, for example, in most cases is not just a visual image but an auditory and perhaps even olfactory presence as well. It is therefore critical to consider the merits of multisensory as opposed to unisensory stimulation in treatment of depression. Recent advances in sensory physiology as noted below necessitate the inclusion of multisensory stimulation in the bottom-up approach to sensory modulation of mood and depression.

Recent developments suggest that the traditional view of separate primary cortical projections for each sensory system which allows for multimodal interactions beyond these primary cortical projection areas is an oversimplification (Beer et al., 2011; Calvert et al., 1999; Meredith et al., 2009; Wallace et al., 2004). In fact, a view has been presented to suggest that there are no separate unisensory primary cortical projections (Ghazanfar & Schroeder, 2006). While this may be a somewhat extreme view at this stage, there is now formidable evidence that there are multisensory neurons in what used to be considered unisensory projection areas (Atilgan et al., 2018; Bizley et al., 2007; Driver & Noesselt, 2008; Gu et al., 2019; Kayser et al., 2008; Schroeder & Foxe, 2005; Teichert & Bolz, 2018).

The mechanism by which peripheral stimulation ameliorates depressive symptomatology has to involve and engage the central neurocircuitry underlying depression. As noted in previous sections, unisensory stimulation can have ameliorative effects on mood and depression. Multisensory stimulation involving more than one sensory system therefore not only will add to the central impact but may also result in synergistic effects since primary sensory cortical areas are also responsive to inputs from other sensory modalities as noted above. Several lines of research involving combination of visual, auditory, olfactory and gustatory stimulation indicate a possible synergistic impact over and above the effects of individual unisensory combinations. There is growing evidence for cross-modal interaction or synergism when stimulation from one modality is combined with that from another (Lalanne & Lorenceau, 2004). After the seminal work by McGurk and MacDonald (1976) that showed a cross-modal interaction between auditory and visual processing, cross-modal interaction and synergism have been reported across a number of sensory combinations as between the auditory system and other sensory modalities such as vision (Chanauria et al., 2019; Ethofer et al., 2006; Kayser et al., 2010; Lovelace et al., 2003; McDonald et al., 2000; McDonald & Ward, 2000; Noesselt et al., 2010; Satoh et al., 2015; Shams et al., 2000; Tivadar et al., 2018; Watanabe &

Shimojo, 2001), olfaction (Castiello et al., 2006; La Buissonnière-Ariza et al., 2012) and gustation (Carvalho et al., 2015, 2016; Knoferle & Spence, 2012; Lin et al., 2019; North, 2012; Yan & Dando, 2015). Similarly, several studies report cross-modal interaction or enhancement between visual stimulation and olfaction (Zellner & Kautz, 1990; Zellner & Whitten, 1999; Gottfried & Dolan, 2003; Michael et al., 2003; Koza et al., 2005; Demattè et al., 2006, Demattè et al., 2009; Seo et al., 2010; Dong & Jacob, 2016) and gustation (Delwiche, 2012; Spence, 2019; Van Beilen et al., 2011). Synergism due to combination of olfactory and gustatory cues is not only constantly experienced almost with each meal or snack but has also been documented by several studies (Djordjevic et al., 2004; Welge-Lüssen et al., 2005) including the case of 'umami', the fifth taste due to the conjunctive effects of monosodium glutamate (MSG) and olfactory cues from foodstuffs resulting in a synergistic enhancement of taste (McCabe & Rolls, 2007; Rolls, 2009).

7 | CONCLUSION AND FUTURE DIRECTIONS

Progress in any area of medicine is achieved with constant search for improved techniques and approaches to treat diseases. The search for new therapeutic solutions becomes urgent with increased evidence that the available cures are not fully successful and even more urgent when the disease begins to afflict large portions of the worldwide population. Depression is at this very critical stage of requiring new therapeutic approaches as it is one of the most prevalent public health problems (Malhi, 2018; Mathers & Loncar, 2006; Rehm & Shield, 2019; World Health Organization, 2017). In view of this exigency, the therapeutic approaches to depression are now considerably more varied than imaginable only a few decades ago. A major tenet and guiding principle of these new approaches is the centrifugal top-down view of both the aetiology and therapeutics of depression. The present paper is not necessarily meant as an alternative to the top-down central account of depression but as a worthy addition to the palette of theorising and clinical practice about the provenance and therapeutics of the psychopathology. The bottom-up view of depression has the added advantage of potentially providing supplementary means of therapeutic vehicles along with the more traditional pharmacotherapeutic approaches. Sensory, particularly multisensory stimulation for purposes of therapy has the added advantage of being inexpensive and, with little precaution, almost free of side effects, two factors that must weigh positively on the minds of both clinicians and patients when considering pharmacotherapies.

A practical starting point for multisensory treatment of depression may be a combination of photic and music stimulation. As noted earlier, light therapy is now a well-established monotherapy for many cases of depression. Pairing of visual and auditory stimuli conveying the same emotion is shown to amplify the affective experience of the viewer and may have therapeutic effect (Baumgartner et al., 2006; da Silva, et al., 2015; Eldar et al., 2007). Because quality, intensity and duration can be practically controlled for photic and auditory stimulation, a combination of light and music therapy is amenable to parametric assessment for achieving optimal synergism in alleviating mood and treating depression.

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CONFLICT OF INTEREST

There is no potential conflict of interest.

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REFERENCES

Aalbers, S., Fusar-Poli, L., Freeman, R. E., Spreen, M., Ket, J. C., Vink, A. C., Maratos, A., Crawford, M., Chen, X. J., & Gold, C. (2017). Music therapy for depression. *Cochrane Database of Systematic Reviews*, *11*, CD004517.

Abbott, A. (2002). Music, maestro, please! *Nature*, *416*, 12–14.

Acevedo, B. P., Aron, E. N., Aron, A., Sangster, M. D., Collins, N., & Brown, L. L. (2014). The highly sensitive brain: An fMRI study of sensory processing sensitivity and response to other's emotions. *Brain and Behavior: A Cognitive Neuroscience Perspective*, *4*, 580–594.

Ackerman, B. H., & Kasbekar, N. (1997). Disturbances of taste and smell induced by drugs. *Pharmacotherapy*, *17*, 482–496.

Adjibade, M., Lemogne, C., Julia, C., Hercberg, S., Galan, P., Assman, K. E., & Kesse-Guyot, E. (2018). Prospective association between adherence to dietary recommendations and incident depressive symptoms in the French NutriNet-Sante cohort. *The British Journal of Nutrition*, *120*, 290–300.

Adolphs, R. (2004). Emotional vision. *Nature Neuroscience*, *7*, 1167–1168.

Akbaraly, T. N., Brunner, E. J., Ferrie, J. E., Marmot, M. G., Kivimaki, M., & Singh-Manoux, A. (2009). Dietary pattern and depressive symptoms in middle age. *The British Journal of Psychiatry*, *195*, 408–413.

Akil, H., Gordon, J., Hen, R., Javitch, J., Mayberg, H., McEwen, B., Maney, M. J., & Nestler, E. J. (2018). Treatment resistant depression: A multiple, systems biology approach. *Neuroscience and Biobehavioral Reviews*, *84*, 272–288.

Albersnagel, F. A. (1988). Velten and musical mood induction procedures: A comparison with accessibility of thought associations. *Behaviour Research and Therapy*, *26*, 79–95.

Al-Karawi, D., & Jubair, L. (2016). Bright light therapy for nonseasonal depression: Meta-analysis of clinical trials. *Journal of Affective Disorders*, *198*, 64–71.

Amsterdam, J. D., Settle, R. G., Doty, R. L., Abelman, E., & Winokur, A. (1987). Taste and smell perception in depression. *Biological Psychiatry*, *22*, 1477–1481.

Andrade, P., Noblesse, L. H. M., Temel, Y., Ackermans, L., Lim, L. W., Steinbusch, H. W. M., & Visser-Vandewalle, V. (2010). Neurostimulatory and ablative treatment in major depressive disorder: A systematic review. *Acta Neurochirurgica*, *152*, 565–577.

Arbisi, P. A., Levine, A. S., Nerenberg, J., & Wolf, J. (1996). Seasonal alteration in taste detection and recognition threshold in seasonal affective disorder: The proximate source of carbohydrate craving. *Psychiatry Research*, *59*, 171–182.

Aron, E., & Aron, A. (1997). Sensory-processing sensitivity and its relation to introversion and emotionality. *Journal of Personality and Social Psychology*, *73*, 345–368.

Aron, E., Aron, A., & Jagiellowicz, J. (2012). Sensory processing sensitivity: A review in the light of the evolution of biological responsivity. *Personality and Social Psychology Review*, *16*, 262–282.

Askalsky, P., & Iosifescu, D. V. (2019). Transcranial photobiomodulation for the management of depression: Current perspectives. *Neuropsychiatric Disease and Treatment*, *15*, 3255–3272.

Asthana, H. S., Mandal, M. K., Khurana, H., & Haque-Nizamiye, S. (1998). Visuospatial and affect recognition deficit in depression. *Journal of Affective Disorders*, *48*, 57–62.

Atanasova, B., Graux, J., El Hage, W., Hommet, C., Camus, V., & Belzung, C. (2008). Olfaction: A potential cognitive marker of psychiatric disorders. *Neuroscience and Biobehavioral Reviews*, *32*, 1315–1325.

Atilgan, H., Town, S. M., Wood, K. C., Jones, G. P., Maddox, R. K., Lee, A. K. C., & Bizley, J. K. (2018). Integration of visual information in auditory cortex promotes auditory scene analysis through multisensory binding. *Neuron*, *97*, 640–655.

Aubert-Khalfa, S., Granier, J. P., Reynaud, E., El Khoury, M., Grosse, E. M., Samuelian, J. C., & Blin, O. (2010). Pure-tone auditory thresholds are decreased in depressed people with post-traumatic stress disorder. *Journal of Affective Disorders*, *127*, 169–176.

Avery, D. H. (1998). A turning point for seasonal affective disorder and light therapy research? *Archives of General Psychiatry*, *55*, 863–864.

Ayres, A. J. (1966). Interrelations among perceptual-motor abilities in a group of normal children. *American Journal of Occupational Therapy*, *20*, 288–292.

Ayres, A. J. (1969). Deficits in sensory integration in educationally handicapped children. *Journal of Learning Disabilities*, *2*, 160–168.

Bar, M., & Neta, M. (2007). Visual elements of subjective preference modulate amygdala activation. *Neuropsychologia*, *45*, 2191–2200.

Baumgartner, T., Lutz, K., Schmidt, C. F., & Jäncke, L. (2006). The emotional power of music: How music enhances the feeling of affective pictures. *Brain Research*, *1075*, 151–164.

Beauchemin, K. M., & Hays, P. (1996). Sunny hospital rooms expedite recovery from severe and refractory depressions. *Journal of Affective Disorders*, *40*, 49–51.

Beer, A. L., Plank, T., & Greenlee, M. W. (2011). Diffusion tensor imaging shows white matter tracts between human auditory and visual cortex. *Experimental Brain Research*, *213*, 299–308.

Bizley, J. K., Nodal, F. R., Bajo, V. M., Nelken, I., & King, A. J. (2007). Physiological and anatomical evidence for multisensory interactions in auditory cortex. *Cerebral Cortex*, *17*, 2172–2189.

Blackburn, T. P. (2019). Depressive disorders: Treatment failures and poor prognosis over the last 50 years. *Pharmacology Research & Perspectives*, e00472–20.

Booker, J. M., Hellekson, C. J., Putilov, A. A., & Danilenko, K. V. (1991). Seasonal Depression and Sleep Disturbances in Alaska and Siberia: A. *Arctic Medical Research* (Supplement:), 281–284.

Bouhuys, A. L., Bloem, G. M., & Groothuis, T. G. (1995). Induction of depression and elated mood by music influences the perception of facial emotional expressions in healthy subjects. *Journal of Affective Disorders*, *33*, 215–216.

Brand, G., & Schaal, B. (2017). L'olfaction dans les troubles dépressifs: Intérêts et perspectives [Olfaction in depressive disorders: Issues and perspectives]. *L'Encephale*, *43*, 176–182.

Brandao, M. L., Coimbra, N. C., & Osaki, M. Y. (2001). Changes in the auditory-evoked potentials induced by fear evoking stimulations. *Physiology & Behavior*, *72*, 365–372.

Breit, S., Kupferberg, A., Rogier, G., & Hasler, G. (2018). Vagus nerve as modulator of the brain-gut axis in psychiatric and inflammatory disorders. *Frontiers in Psychiatry*, *9*, 1–15.

Bruder, G. E., Sutton, S., Babkoff, H., Gurland, B. J., Yozawitz, A., & Fleiss, J. L. (1975). Auditory signal detectability and facilitation of simple reaction time in psychiatric patients and non-patients. *Psychological Medicine*, *5*, 260–272.

Bruder, G. E., Sutton, S., Berger-Gross, P., Quitkin, F., & Davies, S. (1981). Lateralized auditory processing in depression: Dichotic click detection. *Psychiatry Research*, *4*, 253–266.

Bubl, E., Kern, E., Ebert, D., Bach, M., & Van Elst, L. T. (2010). Seeing gray when feeling blue? Depression can be measured in the eye of the diseased. *Biological Psychiatry*, *68*, 205–208.

Budd, R. J., & Pugh, R. (1995). The relationship between locus of control, tinnitus severity, and emotional distress in a group of tinnitus sufferers. *Journal of Psychosomatic Research*, *39*, 1015–1018.

Calvert, G. A., Brammer, M. J., Bullmore, E. T., Campbell, R., Iversen, S. D., & David, A. S. (1999). Response amplification in sensory-specific cortices during crossmodal binding. *NeuroReport*, *10*(12), 2619–2623.

Camilleri, G. M., Méjean, C., Kesse-Guyot, E., Andreeva, V. A., Bellisle, F., Hercberg, S., & Péneau, S. (2014). The associations between emotional eating and consumption of energy-dense snack foods are modified by sex and depressive symptomatology. *The Journal of Nutrition*, *144*, 1264–1273.

Canbeyli, R. (2010). Sensorimotor modulation of mood and depression: An integrative review. *Behavioural Brain Research*, *207*, 249–264.

Canbeyli, R. (2013). Sensorimotor modulation of mood and depression: In search of an optimal mode of stimulation. *Frontiers in Human Neuroscience*, *7*(428), 1–13.

Carreno, F. R., & Frazer, A. (2017). Vagal stimulation for treatment-resistant depression. *Neurotherapeutics*, *14*, 716–727.

Carter, A. S., Ben-Sasson, A., & Briggs-Gowan, M. J. (2011). Sensory over responsivity, psychopathology, and family impairment in school-aged children. *Journal of the American Academy of Child and Adolescent Psychiatry*, *50*, 1210–1219.

Carvalho, F. R., Van Ee, R., Rychtarikova, M., Touhafi, A., Steenhaut, K., Persoone, D., & Spence, C. (2015). Using sound-taste correspondences to enhance the subjective value of tasting experience. *Frontiers in Psychology*, *6*(1309), 1–8.

Carvalho, F. R., Velasco, C., Van Ee, R., LeBoeuf, Y., & Spence, C. (2016). Music influences hedonic and taste ratings in beer. *Frontiers in Psychology*, *7*(636), 1–12.

Castiello, U., Zucco, G. M., Parma, V., Ansuini, C., & Tirindelli, R. (2006). Cross-modal interactions between olfaction and vision when grasping. *Chemical Senses*, *31*, 665–671.

Chanauria, N., Bharmauria, V., Bachatene, L., Cattan, S., Rouat, J., & Molotchnikoff, S. (2019). Sound induces change in orientation preference of V1 neurons: Audio-visual cross-influence. *Neurosci.*, *404*, 48–61.

Choi, A. N., Lee, M. S., & Lim, H. J. (2008). Effects of group music intervention on depression, anxiety, and relationships in psychiatric patients: A pilot study. *Journal of Alternative and Complementary Medicine*, *14*, 567–570.

Christensen, L. (1997). The effect of carbohydrates on affect. *Nutrition*, *13*, 503–514.

Clark, D. M. (1983). On the induction of depressed mood in the laboratory: Evaluation and comparison of the Velten and musical procedures. *Advances in Behaviour Research and Therapy*, *5*, 27–49.

Collet, L., & Duclaux, R. (1986). An auditory psychophysical correlate of depression. *International Journal of Psychophysiology*, *3*, 205–210.

Conway, C. R., & Xiong, W. (2018). The mechanism of action of vagus nerve stimulation in treatment-resistant depression: Current conceptualizations. *The Psychiatric Clinics of North America*, *41*, 395–407.

Cosker, E., Schwan, R., Angioi-Duprez, K., Laprevote, V., & Schwitzer, T. (2020). New insights on the role of the retina in diagnostic and therapeutic strategies in major depressive disorder. *Neuroscience and Biobehavioral Reviews*, *113*, 262–272.

Croom, A. M. (2012). Music, neuroscience, and the psychology of well-being. *Frontiers in Psychology*, *2*(393), 1–15.

Croy, I., & Hummel, T. (2017). Olfaction as a marker for depression. *Journal of Neurology*, *264*, 631–638.

Croy, I., Symmank, A., Schellong, J., Hummel, C., Gerber, J., Joraschky, P., & Hummel, T. (2014). Olfaction as a marker for depression in humans. *Journal of Affective Disorders*, *160*, 80–86.

Cryan, J. F., & Dinan, T. G. (2012). Mind-altering microorganisms: The impact of the gut microbiota on brain and behaviour. *Nature Reviews. Neuroscience*, *13*, 701–712.

Czéh, B., Fuchs, E., Wiborg, O., & Simon, M. (2016). Animal models of major depression and their clinical implications. *Progress in Neuro-Psychopharmacology & Biological Psychiatry*, *64*, 293–310.

da Silva, V. F., Ribeiro, A. P., dos Santos, V. A., Nardi, A. E., Spear King, A. L., & Calomeni, M. R. (2015). Stimulation by light and sound: Therapeutics effects in humans. Systematic review. *Clinical Practice and Epidemiology in Mental Health*, *2015*(11), 150–154.

Dandekar, M. P., Fenoy, A. J., Carvalho, A. F., Soares, J. C., & Quevedo, J. (2018). Deep brain stimulation for treatment-resistant depression: An integrative review of preclinical and clinical findings and translational implications. *Molecular Psychiatry*, *23*, 1094–1112.

Danion, J. M., Weingartner, H., & Singer, L. (1996). Is cognitive psychopathology plausible: Illustrations from memory research. *Canadian Journal of Psychiatry*, *41*(7 Suppl 1), S5–S13.

de Kloet, E. R., Otte, C., Kumsta, R., Kok, L., Hillegers, M. H., Hasselmann, H., Kliegel, D., & Joëls, M. (2016). Stress and depression: A crucial role of the mineralocorticoid receptor. *Journal of Neuroendocrinology*, *28*(8), 1–12, jne12379. https://doi.org/10.1111/jne.12379

Delwiche, J. F. (2012). You eat with your eyes first. *Physiology & Behavior*, *107*, 502–504.

Demattè, M. L., Sanabria, D., & Spence, C. (2006). Cross-modal associations between odors and colors. *Chemical Senses*, *31*, 531–538.

Demattè, M. L., Sanabria, D., & Spence, C. (2009). Olfactory discrimination: When vision matters? *Chemical Senses*, *34*, 103–109.

Desseilles, M., Balteau, E., Sterpenich, V., Dang-Vu, T. T., Darsaud, A., Vandewalle, G., Albouy, G., Salmon, E., Peters, F., Schmidt, C., Schabus, M., Gais, S., Degueldre, C., Phillips, C., Luxen, A., Ansseau, M., Maquet, P., & Schwartz, S. (2009). Abnormal neural filtering of irrelevant visual information in depression. *The Journal of Neuroscience*, *29*, 1395–1403.

Dinan, T. G., & Cryan, J. F. (2013). Melancholic microbes: A link between gut microbiota and depression? *Neurogastroenterology and Motility*, *25*, 713–719.

Dinan, T. G., & Cryan, J. F. (2017). Brain-gut-microbiota axis and mental health. *Psychosomatic Medicine*, *79*, 920–926.

Disner, S. G., Beevers, C. G., Haigh, E. A. P., & Beck, A. T. (2011). Neural mechanisms of the cognitive model of depression. *Nature Reviews Neuroscience*, *12*, 467–477.

Djordjevic, J., Zatorre, R. J., & Jones-Gotman, M. (2004). Odor-induced changes in taste perception. *Experimental Brain Research*, *159*, 405–408.

Dong, S., & Jacob, T. J. (2016). Combined non-adaptive light and smell stimuli lowered blood pressure, reduced heart rate and reduced negative affect. *Physiology & Behavior*, *156*, 94–105.

Doose-Grünefeld, S., Eickhoff, S. B., & Müller, V. I. (2015). Audiovisual emotional processing and neurocognitive functioning in patients with depression. *Frontiers in Integrative Neuroscience*, *9*, 3.

Driver, J., & Noesselt, T. (2008). Multisensory interplay reveals crossmodal influences on 'sensory-specific' brain regions, neural responses, and judgments. *Neuron*, *57*, 11–23.

Duman, R. S., Sanacora, G., & Krystal, J. H. (2019). Altered connectivity in depression: GABA and glutamate neurotransmitter deficits and reversal by novel treatments. *Neuron*, *102*, 75–90.

Ekstrand, B., Young, J. F., & Rasmussen, M. K. (2017). Taste receptors in the gut—A new target for health promoting properties in diet. *Food Research International*, *100*(Pt. 2), 1–8.

Eldar, E., Ganor, O., Admon, R., Bleich, A., & Hendler, T. (2007). Feeling the real world: Limbic response to music depends on related content. *Cerebral Cortex*, *17*, 2828–2840.

Engel-Yeger, B., & Dunn, W. (2011). The relationship between sensory processing difficulties and anxiety level of healthy adults. *British Journal of Occupational Therapy*, *74*, 210–216.

Engel-Yeger, B., Gonda, X., Muzio, C., Rinosi, G., Pompili, M., Amore, M., & Serafini, G. (2016). Sensory processing patterns, coping strategies, and quality of life among patients with unipolar and bipolar disorders. *Brazilian Journal of Psychiatry*, *38*, 207–215.

Engel-Yeger, B., Muzio, C., Rinosi, G., Solano, P., Geoffroy, P. A., Pompili, M., Amore, M., & Serafini, G. (2016). Extreme sensory processing patterns and their relation with clinical conditions among individuals with major affective disorders. *Psychiatry Research*, *236*, 112–118.

Erhan, H., Borod, J. C., Tenke, C. E., & Bruder, G. E. (1998). Identification of emotion in a dichotic listening task: Event-related brain potential and behavioral findings. *Brain and Cognition*, *37*, 286–307.

Erkkilä, J., Punkanen, M., Fachner, J., Ala-Ruona, E., Pöntiö, I., Tervaniemi, M., Vanhala, M., & Gold, C. (2011). Individual music therapy for depression: Randomised controlled trial. *The British Journal of Psychiatry*, *199*, 132–139.

Espiritu, R. C., Kripke, D. F., Ancoli-Israel, S., Mowen, M. A., Mason, W. J., Fell, R. L., Klauber, M. R., & Kaplan, O. J. (1994). Low illumination experienced by San Diego adults: Association with atypical depressive symptoms. *Biological Psychiatry*, *106*, 780–786.

Ethofer, T., Anders, S., Erb, M., Droll, C., Royen, L., Saur, R., Reiterer, S., Grodd, W., & Wildgruber, D. (2006). Impact of voice on emotional judgment of faces: An event-related fMRI study. *Human Brain Mapping*, *27*, 707–714.

Even, C., Schröder, C. M., Friedman, S., & Rouillon, F. (2008). Efficacy of light therapy in nonseasonal depression: A systematic review. *Journal of Affective Disorders*, *108*, 11–23.

Ferneyhough, E., Kim, M. K., Phelps, E. A., & Carrasco, M. (2013). Anxiety modulates the effects of emotion and attention on early vision. *Cognition and Emotion*, *27*, 166–176.

Field, T., Diego, M., Hernandez-Reif, M., Cisneros, W., Feijo, L., & Vera, Y. (2005). Lavender fragrance cleansing gel effects on relaxation. *The International Journal of Neuroscience*, *115*, 207–222.

Fitzgerald, P. J. (2013). Gray colored glasses: Is major depression partially a sensory perceptual disorder? *Journal of Affective Disorders*, *151*, 418–422.

Flohr, E. L. R., Erwin, E., Croy, I., & Hummel, T. (2017). Sad man's nose: Emotion induction and olfactory perception. *Emotion*, *17*, 369–378.

Freeborough, A., & Kimpton, J. (2011). Discovering new genetic and psychosocial pathways in Major Depressive Disorder: The NewMood project. *Psychiatria Danubina*, *23*(Suppl 1), S138–S141.

Gagner-Tjellesen, D., Yurkovich, E., & Gragert, M. (2001). Use of music therapy and other ITNIs in acute care. *Journal of Psychosocial Nursing and Mental Health Services*, *39*, 26–37.

García-Blanco, T., Dávalos, A., & Visioli, F. (2017). Tea, cocoa, coffee, and affective disorders: Vicious or virtuous cycle? *Journal of Affective Disorders*, *224*, 61–68.

Garg, A. X., Marshall, J., Salvadori, M., Thiessen-Philbrook, H. R., Macnab, J., Suri, R. S., Haynes, R. B., Pope, J., William Clark, W., & Walkerton Health Study Investigators. (2006). A gradient of acute gastroenteritis was characterized, to assess risk of long-term health sequelae after drinking bacterial-contaminated water. *Journal of Clinical Epidemiology*, *59*, 421–428.

Gasper, K., & Clore, G. L. (2002). Attending to the big picture: mood and global versus local processing of visual information. *Psychological Science*, *13*, 34–40.

GBD 2017 Disease and injury incidence and prevalence collaborators. (2018). Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990-2017: A systematic analysis for the Global Burden of Disease Study 2017. *Lancet*, *392*, 1789–1858.

George, M. S., Nahas, Z., Bohning, D. E., Kozel, F. A., Anderson, B., Chae, J. H., Lomarev, M., Denslow, S., Li, X., & Mu, C. M. D. P. (2002). Vagus nerve stimulation therapy: A research update. *Neurology*, *59*(6 Suppl 4), S56–S61.

Ghazanfar, A. A., & Schroeder, C. E. (2006). Is neocortex essentially multisensory? *Trends in Cognitive Sciences*, *10*, 278–285.

Glass, S. T., & Heuberger, E. (2016). Effects of a pleasant natural odor on mood: No influence of age. *Natural Product Communications*, *11*, 1555–1559.

Goel, N., & Etwaroo, G. R. (2006). Bright light, negative ions and auditory stimuli produce rapid mood changes in a student population: A placebo-controlled study. *Psychological Medicine*, *36*, 1253–1263.

Goel, N., & Grasso, D. J. (2004). Olfactory discrimination and transient mood change in young men and women: Variation by season, mood state, and time of day. *Chronobiology International*, *21*, 691–719.

Gold, C., Solli, H. P., Krüger, V., & Lie, S. A. (2009). Dose-response relationship in music therapy for people with serious mental disorders: Systematic review and meta-analysis. *Clinical Psychology Review*, *29*, 193–207.

Golomb, J. D., McDavitt, J. R., Ruf, B. M., Chen, J. I., Saricicek, A., Maloney, K. H., Hu, J., Chun, M. M., & Bhagwagar, Z. (2009). Enhanced visual motion perception in major depressive disorder. *The Journal of Neuroscience*, *29*, 9072–9077.

Gomez, P., & Danuser, B. (2004). Affective and physiological responses to environmental noises and music. *International Journal of Psychophysiology*, *53*, 91–103.

Gonda, X., Pompili, M., Serafini, G., Carvalho, A. F., Rihmer, Z., & Dome, P. (2015). The role of cognitive dysfunction in the symptoms and remission from depression. *Annals of General Psychiatry*, *14*, 27.

Gottfried, J. A., & Dolan, R. J. (2003). The nose smells what the eye sees: Crossmodal visual facilitation of human olfactory perception. *Neuron*, *39*, 375–386.

Grahek, I., Shenhav, A., Musslick, S., Krebs, R. M., & Koster, E. (2019). Motivation and cognitive control in depression. *Neuroscience and Biobehavioral Reviews*, *102*, 371–381.

Grases, G., Colom, M. A., Sanchis, P., & Grases, F. (2019). Possible relation between consumption of different food groups and depression. *BMC Psychology*, *7*, 14.

Gross-Isseroff, R., Luca-Haimovici, K., Sasson, Y., Kindler, S., Kotler, M., & Zohar, J. (1994). Olfactory sensitivity in major depressive disorder and obsessive compulsive disorder. *Biological Psychiatry*, *35*, 798–802.

Gu, J., Liu, B., Li, X., Wang, P., & Wang, B. (2019). Cross-modal representations in early visual and auditory cortices revealed by multi-voxel pattern analysis. *Brain Imaging and Behavior*, *13*, 1–13.

Guo, X., Park, Y., Freedman, N. D., Sinha, R., Hollenbeck, A. R., Blair, A., & Chen, H. (2014). Sweetened beverages, coffee, and tea and depression risk among older US adults. *PLoS ONE*, *9*, e94715.

Guzel Ozdemir, P., Boysan, M., Smolensky, M. H., Selvi, Y., Aydin, A., & Yilmaz, E. (2015). Comparison of venlafaxine alone versus venlafaxine plus bright light therapy combination for severe major depressive disorder. *The Journal of Clinical Psychiatry*, *76*, e645–e654.

Haglund, M. E., Nestadt, P. S., Cooper, N. S., Southwick, S. M., & Charney, D. S. (2007). Psychobiological mechanisms of resilience: Relevance to prevention and treatment of stress-related psychopathology. *Development and Psychopathology*, *19*, 889–920.

Han, J. H., Lee, H. J., Jung, J., & Park, E. C. (2019). Effects of self-reported hearing or vision impairment on depressive symptoms: A population-based longitudinal study. *Epidemiology and Psychiatric Sciences*, *28*, 343–355.

Han, M. H., & Nestler, E. J. (2017). Neural substrates of depression and resilience. *Neurotherapeutics*, *14*, 677–686.

Hao, Y., Ge, H., Sun, M., & Gao, Y. (2019). Selecting an appropriate animal model of depression. *International Journal of Molecular Sciences*, *20*, 4827.

Heath, T. P., Melichar, J. K., Nutt, D. J., & Donaldson, L. F. (2006). Human taste thresholds are modulated by serotonin and noradrenaline. *The Journal of Neuroscience*, *26*, 12664–12671.

Heise, S., Steinberg, H., & Himmerich, H. (2013). Die Diskussion um die Anwendung und die Wirksamkeit von Musik bei depressiven Störungen in Geschichte und Gegenwart. *Fortschritte der Neurologie-Psychiatrie*, *81*, 426–436.

Hill, A. J., & Heaton-Brown, L. (1994). The experience of food craving: a prospective investigation in healthy women. *Journal of Psychosomatic Research*, *38*, 801–814.

Hill, A. J., Weaver, C. F. L., & Blundell, J. E. (1991). Food craving, dietary restraint and mood. *Appetite*, *17*, 187–197.

Hillecke, T., Nickel, A., & Bolay, H. V. (2005). Scientific perspectives on music therapy. *Annals of the New York Academy of Sciences*, *1060*, 271–282.

Hjordt, L. V., & Stenbæk, D. S. (2019). Sensory processing sensitivity and its association with seasonal affective disorder. *Psychiatry Research*, *272*, 359–364.

Hoenen, M., Wolf, O. T., & Pause, B. M. (2017). The impact of stress on odor perception. *Perception*, *46*, 366–376.

Hsu, W. C., & Lai, H. L. (2004). Effects of music on major depression in psychiatric inpatients. *Archives of Psychiatric Nursing*, *18*, 193–199.

Hur, K., Choi, J. S., Zheng, M., Shen, J., & Wrobel, B. (2018). Association of alterations in smell and taste with depression in older adults. *Laryngoscope Investigative Otolaryngology*, *3*, 94–99.

Jackson, S. E., Smith, L., Firth, J., Grabovac, I., Soysal, P., Koyanagi, A., Hu, L., Stubbs, B., Demurtas, J., Veronese, N., Zhu, X., & Yang, L. (2019). Is there a relationship between chocolate consumption and symptoms of depression? A cross-sectional survey of 13,626 US adults. *36*, 987–995.

Jean-Louis, G., Kripke, D., Cohen, C., Zizi, F., & Wolintz, A. (2005). Associations of ambient illumination with mood: Contribution of ophthalmic dysfunctions. *Physiology & Behavior*, *84*, 479–487.

Jiang, H., Ling, Z., Zhang, Y., Mao, H., Ma, Z., Yin, Y., Wang, W., Tang, W., Tan, Z., Shi, J., Li, L., & Ruan, B. (2015). Altered fecal microbiota composition in patients with major depressive disorder. *Brain, Behavior, and Immunity*, *48*, 186–194.

Johnson, O., & Crockett, D. (1982). Changes in perceptual asymmetries with clinical improvement of depression and schizophrenia. *Journal of Abnormal Psychology*, *91*, 45–54.

Johnston, K. M., Powell, L. C., Anderson, I. M., Szabo, S., & Cline, S. (2019). The burden of treatment-resistant depression: A systematic review of the economic and quality of life literature. *Journal of Affective Disorders*, *242*, 195–210.

Jones, C., & Nemeroff, C. B. (2021). Precision Psychiatry: Biomarker-guided tailored therapy for effective treatment and prevention in major depression. *Adv. Exp. Med. Biol.*, *1305*, 535–563.

Kadohisa, M. (2013). Effects of odor on emotion, with implications. *Frontiers in Systems Neuroscience*, *7*, 66.

Kampov-Polevoy, A. B., Alterman, A., Khalitov, E., & Garbutt, J. C. (2006). Sweet preference predicts mood altering effect of and impaired control over eating sweet foods. *Eating Behaviors*, *7*, 181–187.

Kayser, C., Logothetis, N. K., & Panzeri, S. (2010). Visual enhancement of the information representation in auditory cortex. *Current Biology*, *20*, 19–24.

Kayser, C., Petkov, C. I., & Logothetis, N. K. (2008). Visual modulation of neurons in auditory cortex. *Cerebral Cortex*, *18*, 1560–1574.

Kelly, J. R., Clarke, G., Cryan, J. F., & Dinan, T. G. (2016). Brain-gut-microbiota axis: challenges for translation in psychiatry. *Annals of Epidemiology*, *26*, 366–372.

Kemper, K. J., & Danhauer, S. C. (2005). Music as therapy. *Southern Medical Journal*, *98*, 282–288.

Kessler, R. C. (2012). The costs of depression. *Psychiatric Clinics*, *35*, 1–14.

Khil, L., Rahe, C., Wellmann, J., Baune, B. T., Wersching, H., & Berger, K. (2016). Association between major depressive disorder and odor identification impairment. *Journal of Affective Disorders*, *203*, 332–338.

Kiecolt-Glaser, J. K., Graham, J. E., Malarkey, W. B., Porter, K., Lemeshow, S., & Glaser, R. (2008). Olfactory influences on mood and autonomic, endocrine, and immune function. *Psychoneuroendocrinology*, *33*, 328–339.

Kisely, S., Li, A., Warren, N., & Siskind, D. (2018). A systematic review and meta-analysis of deep brain stimulation for depression. *Depression and Anxiety*, *35*, 468–480.

Klengel, T., & Binder, E. B. (2013). Gene × environment interactions in the prediction of response to antidepressant treatment. *The International Journal of Neuropsychopharmacology*, *16*, 701–711.

Knasko, S. C. (1992). Ambient odor's effect on creativity, mood, and perceived health. *Chemical Senses*, *17*, 27–35.

Knoferle, K., & Spence, C. (2012). Crossmodal correspondences between sounds and tastes. *Psychonomic Bulletin & Review*, *19*, 992–1006.

Knuppel, A., Shipley, M. J., Llewellyn, C. H., & Brunner, E. J. (2017). Sugar intake from sweet food and beverages, common mental disorder and depression: Prospective findings from the Whitehall II study. *Scientific Reports*, *7*, 1–10.

Kohler, C. G., Hoffman, L. J., Eastman, L. B., Healey, K., & Moberg, P. J. (2011). Facial emotion perception in depression and bipolar disorder: A quantitative review. *Psychiatry Research*, *188*, 303–309.

Kohli, P., Soler, Z. M., Nguyen, S. A., Muus, J. S., & Schlosser, R. J. (2016). The association between olfaction and depression: A systematic review. *Chemical Senses*, *41*, 479–486.

Komori, T., Fujiwara, R., Tanida, M., Nomura, J., & Yokoyama, M. M. (1995). Effects of citrus fragrance on immune function and depressive states. *Neuroimmunomodulation*, *2*, 174–180.

Kontaris, I., East, B. S., & Wilson, D. A. (2020). Behavioral and neurobiological convergence of odor, mood and emotion: A review. *Frontiers in Behavioral Neuroscience*, *14*, 35.

Koza, B. J., Cilmi, A., Dolese, M., & Zellner, D. A. (2005). Color enhances orthonasal olfactory intensity and reduces retronasal olfactory intensity. *Chemical Senses*, *30*, 643–649.

Krauchi, K., & Wirz-Justice, A. (1988). The four seasons: food intake frequency in seasonal affective disorder in the course of a year. *Psychiatry Research*, *25*, 233–238.

Kripke, D. F. (1998). Light treatment for nonseasonal depression: Speed, efficacy, and combined treatment. *Journal of Affective Disorders*, *49*, 109–117.

Krishnan, V., & Nestler, E. J. (2010). Linking molecules to mood: New insight into the biology of depression. *The American Journal of Psychiatry*, *167*, 1305–1320.

Krishnan, V., & Nestler, E. J. (2011). Animal models of depression: Molecular perspectives. *Current Topics in Behavioral Neurosciences*, *7*, 121–147.

La Buissonnière-Ariza, V., Frasnelli, J., Collignon, O., & Lepore, F. (2012). Olfactory priming leads to faster sound localization. *Neuroscience Letters*, *506*, 188–192.

Lach, G., Schellekens, H., Dinan, T. G., & Cryan, J. F. (2018). Anxiety, depression, and the microbiome: A role for gut peptides. *Neurotherapeutics*, *15*, 36–59.

Lalanne, C., & Lorenceau, J. (2004). Crossmodal integration for perception and action. *The Journal of Physiology*, *98*, 265–279.

Lane, J. D., Kasian, S. J., Owens, J. E., & Marsh, G. R. (1998). Binaural auditory beats affect vigilance performance and mood. *Physiology & Behavior*, *63*, 249–252.

Langguth, B., Landgrebe, M., Kleinjung, T., Sand, G. P., & Hajak, G. (2011). Tinnitus and depression. *The World Journal of Biological Psychiatry*, *12*, 489–500.

Laudien, J. H., Küster, D., Sojka, B., Ferstl, R., & Pause, B. M. (2006). Central odor processing in subjects experiencing helplessness. *Brain Research*, *1120*, 141–150.

Lavoie, M. P., Lam, R. W., Bouchard, G., Sasseville, A., Charron, M. C., Gagné, A. M., Tremblay, P., Filteau, M. J., & Hébert, M. (2009). Evidence of a biological effect of light therapy on the retina of patients with seasonal affective disorder. *Biological Psychiatry*, *66*, 253–258.

Le Port, A., Gueguen, A., Kesse-Guyot, E., Melchior, M., Lemogne, C., Nabi, H., Goldberg, M., Zins, M., & Czernichow, S. (2012). Association between dietary patterns and depressive symptoms over time: a 10-year follow-up study of the GAZEL cohort. *PLoS ONE*, *7*, e51593.

Lee, B. T., Cho, S. W., Khang, H. S., Lee, B. C., Choi, I. G., Lyoo, I. K., & Ham, B. J. (2007). The neural substrates of affective processing toward positive and negative affective pictures in patients with major depressive disorder. *Progress in Neuro-Psychopharmacology & Biological Psychiatry*, *31*, 1487–1492.

Lehrner, J., Eckersberger, C., Walla, P., Pötsch, G., & Deecke, L. (2000). Ambient odor of orange in a dental office reduces anxiety and improves mood in female patients. *Physiology & Behavior*, *71*, 83–86.

Lehrner, J., Marwinski, G., Lehr, S., Johren, P., & Deecke, L. (2005). Ambient odors of orange and lavender reduce anxiety and improve mood in a dental office. *Physiology & Behavior*, *86*, 92–95.

Leigh, I. W., & Anthony-Tolbert, S. (2001). Reliability of the BDI-II with deaf persons. *Rehabilitation Psychology*, *29*, 195–202.

Leijssen, J. B., Snijder, M. B., Timmermans, E. J., Generaal, E., Stronks, K., & Kunst, A. E. (2019). The association between road traffic noise and depressed mood among different ethnic and socioeconomic groups. The HELIUS study. *International Journal of Hygiene and Environmental Health*, *222*, 221–229.

Leppämäki, S., Partonen, T., & Lönnqvist, J. (2002). Bright-light exposure combined with physical exercise elevates mood. *Journal of Affective Disorders*, *72*, 139–144.

Leppänen, J. M., Milders, M., Bell, J. S., Terriere, E., & Hietanen, J. K. (2004). Depression biases the recognition of emotionally neutral faces. *Psychiatry Research*, *128*, 123–133.

Leubner, D., & Hinterberger, T. (2017). Reviewing the effectiveness of music interventions in treating depression. *Frontiers in Psychology*, *8*, 1109.

Lewy, A. J., Kern, H. A., Rosenthal, N. E., & Wehr, T. A. (1982). Bright artificial light treatment of a manic-depressive patient with a seasonal mood cycle. *The American Journal of Psychiatry*, *139*, 1496–1498.

Li, Y., Lv, M. R., Wei, Y. J., Sun, L., Zhang, J. X., Zhang, H. G., & Li, B. (2017). Dietary patterns and depression risk: A meta-analysis. *Psychiatry Research*, *253*, 373–382.

Liljas, A. E. M., Jones, A., Cadar, D., Steptoe, A., & Lassale, C. (2020). Association of multisensory impairment with quality of life and depression in English older adults. *JAMA Otolaryngology. Head & Neck Surgery*, *146*, 278–285.

Lin, S. T., Yang, P., Lai, C. Y., Su, Y. Y., Yeh, Y. C., Huang, M. F., & Chen, C. C. (2011). Mental health implications of music: Insight from neuroscientific and clinical studies. *Harvard Review of Psychiatry*, *19*, 34–46.

Lin, Y., Hsuan, T., Hamid, N., Shepherd, D., Kantono, K., & Spence, C. (2019). Environmental sounds influence the multisensory perception of chocolate gelati. *Food*, *8*, 124.

Lionetti, F., Aron, A., Aron, E. N., Burns, G. L., Jagiellowicz, J., & Pluess, M. (2018). Dandelions, tulips and orchids: Evidence for the existence of low-sensitive, medium-sensitive and high-sensitive individuals. *Translational Psychiatry*, *8*, 24.

Liss, M., Timmel, L., Baxley, K., & Killingsworth, P. (2005). Sensory processing sensitivity and its relation to parental bonding, anxiety, and depression. *Personality & Individual Differences*, *39*, 1429–1439.

Liu, X., Yan, Y., Li, F., & Zhang, D. (2016). Fruit and vegetable consumption and the risk of depression: A meta-analysis. *Nutrition*, *32*, 296–302.

Lolij, J., & Meurs, M. (2011). Music alters visual perception. *PLoS ONE*, *6*, e1886.

Lombion-Pouthier, S., Vandel, P., Nezelof, S., Haffen, E., & Millot, J. L. (2006). Odor perception in patients with mood disorders. *Journal of Affective Disorders*, *90*, 187–191.

Lovelace, C. T., Stein, B. E., & Wallace, M. T. (2003). An irrelevant light enhances auditory detection in humans: a psychophysical analysis of multisensory integration in stimulus detection. *Brain Research. Cognitive Brain Research*, *17*, 447–453.

Lowe, B., Andresen, V., Fraedrich, K., Gappmayer, K., Wegscheider, K., Treszl, A., Riegel, B., Rose, M., Lohse, A. W., & Broicher, W. (2014). Psychological outcome, fatigue, and quality of life after infection with shiga toxin-producing Escherichia coli O104. *Clinical Gastroenterology and Hepatology*, *12*, 1848–1855.

Lozupone, C. A., Stombaugh, J. I., Gordon, J. I., Jansson, J. K., & Knight, R. (2012). Diversity, stability and resilience of the human gut microbiota. *Nature*, *489*, 220–230.

Macht, M., & Dettmer, D. (2006). Everyday mood and emotions after eating a chocolate bar or an apple. *Appetite*, *46*, 332–336.

Macht, M., & Mueller, J. (2007). Immediate effects of chocolate on experimentally induced mood states. *Appetite*, *49*, 667–674.

Mackert, A., Volz, H. P., Stieglitz, R. D., & Muller-Oerlinghausen, B. (1991). Phototherapy in nonseasonal depression. *Biological Psychiatry*, *30*, 257–268.

Magilvy, J. K. (1985). Experiencing hearing loss in later life: A comparison of deaf and hearing-impaired older women. *Research in Nursing & Health*, *8*, 347–353.

Malhi, G. S. (2018). Depression. *Lancet*, *392*, 2299–2312.

Malone, J. R., & Hemsley, D. R. (1977). Lowered responsiveness and auditory signal detectability during depression. *Psychological Medicine*, *7*, 717–722.

Mathers, C. D., & Loncar, D. (2006). Projections of global mortality and burden of disease from 2002 to 2030. *PLoS Medicine*, *3*, e442.

Matsubara, E., & Ohira, T. (2018). Inhalation of Japanese cedar (Cryptomeria japonica) wood odor causes psychological relaxation after monotonous work among female participants. *Biomedical Research*, *39*, 241–249.

Matveychuk, D., Thomas, R. K., Swainson, J., Khullar, A., MacKay, M. A., Baker, G. B., & Dursun, S. M. (2020). Ketamine as an antidepressant: Overview of its mechanisms of action and potential predictive biomarkers. *Therapeutic Advances in Psychopharmacology*, *10*, 1–21.

McCabe, C., & Rolls, E. T. (2007). Umami: A delicious flavor formed by convergence of taste and olfactory pathways in the human brain. *The European Journal of Neuroscience*, *25*, 1855–1864.

McCaffrey, R. J., Duff, K., & Solomon, G. S. (2000). Olfactory dysfunction discriminates probable Alzheimer's dementia from major depression: A cross-validation and extension. *The Journal of Neuropsychiatry and Clinical Neurosciences*, *12*, 29–33.

McDonald, J. J., Teder-Sälejärvi, W. A., & Hillyard, S. A. (2000). Involuntary orienting to sound improves visual perception. *Nature*, *407*, 906–908.

McDonald, J. J., & Ward, L. M. (2000). Involuntary listening aids seeing: Evidence from human electrophysiology. *Psychological Science*, *11*, 167–171.

McEwen, B. S., Bowles, N. P., Gray, J. D., Hill, M. N., Hunter, R. G., Karatsoreos, I. N., & Nasca, C. (2015). Mechanisms of stress in the brain. *Nature Neuroscience*, *18*, 1353–1363.

McGurk, H., & MacDonald, J. (1976). Hearing lips and seeing voices. *Nature*, *264*, 746–748.

McMahon, K., Anand, D., Morris-Jones, M., & Rosenthal, M. Z. (2019). A path from childhood sensory processing disorder to anxiety disorders: The mediating role of emotion dysregulation and adult sensory processing disorder symptoms. *Frontiers in Integrative Neuroscience*, *13*, 22.

Meier, B. P., Noll, S. W., & Molokwu, O. J. (2017). The sweet life: The effect of mindful chocolate consumption on mood. *Appetite*, *108*, 21–27.

Meier, B. P., Robinson, M. D., Crawford, L. E., & Ahlvers, W. J. (2007). When "light" and "dark" thoughts become light and dark responses: Affect biases brightness judgments. *Emotion*, *7*, 366–377.

Ménard, C., Hodes, G. E., & Russo, S. J. (2016). Pathogenesis of depression: Insights from human and rodent studies. *Neurosci.*, *321*, 138–162.

Meredith, M. A., Allman, B. L., Keniston, L. P., & Clemo, H. R. (2009). Auditory influences on non-auditory cortices. *Hearing Research*, *258*, 64–71.

Michael, G. A., Jacquot, L., Millot, J. L., & Brand, G. (2003). Ambient odors modulate visual attentional capture. *Neuroscience Letters*, *352*, 221–225.

Michael, N., Ostermann, J., Sörös, P., Schwindt, W., & Pfleiderer, B. (2004). Altered habituation in the auditory cortex in a subgroup of depressed patients by functional magnetic resonance imaging. *Neuropsychobiology*, *49*, 5–9.

Miller, L. J., Nielsen, D. M., Schoen, S. A., & Brett-Green, B. A. (2009). Perspectives on sensory processing disorder: A call for translational research. *Frontiers in Integrative Neuroscience*, *3*, 22.

Miller, S. M., & Naylor, G. J. (1989). Unpleasant taste-a neglected symptom in depression. *Journal of Affective Disorders*, *17*, 291–293.

Mohammadi, R., Hosseini-Safa, A., Ehsani Ardakani, M. J., & Rostami-Nejad, M. (2015). The relationship between intestinal parasites and some immune-mediated intestinal conditions. *Gastroenterology and Hepatology From Bed to Bench*, *8*(2), 123–131.

Molendijk, M., Molero, P., Ortuño Sánchez-Pedreño, F., Van der Does, W., & Angel Martínez-González, M. (2018). Diet quality and depression risk: A systematic review and dose-response meta-analysis of prospective studies. *Journal of Affective Disorders*, *226*, 346–354.

Morkl, S., Wagner-Skacel, J., Lahousen, T., Lackner, S., Holasek, S. J., Bengesser, S. A., Painold, A., Holl, A. K., & Reininghaus, E. (2018). The role of nutrition and the gut-brain axis in psychiatry: A review of the literature. *Neuropsychobiology*, *79*, 80–88.

Muller, V. I., Cieslik, E. C., Kellermann, T. S., & Eickhoff, S. B. (2014). Crossmodal emotional integration in major depression. *Social Cognitive and Affective Neuroscience*, *9*, 839–848.

Murrough, J. W., & Charney, D. S. (2012). Is there anything really novel on the antidepressant horizon? *Current Psychiatry Reports*, *14*, 643–649.

Naranjo, C., Kornreich, C., Campanella, S., Noël, X., Vandriette, Y., Gillain, B., de Longueville, X., Delatte, B., Verbanck, P., & Constant, E. (2011). Major depression is associated with impaired processing of emotion in music as well as in facial and vocal stimuli. *Journal of Affective Disorders*, *128*, 243–251.

Naseribafrouei, A., Hestad, K., Avershina, E., Sekelja, M., Linløkken, A., Wilson, A. R., & Rudi, K. (2014). Correlation between the human fecal microbiota and depression. *Neurogastroenterology and Motility*, *26*, 1155–1162.

Negoias, S., Croy, I., Gerber, J., Puschmann, S., Petrowski, K., Joraschky, P., & Hummel, T. (2010). Reduced olfactory bulb volume and olfactory sensitivity in patients with acute major depression. *Neuroscience*, *169*, 415–421.

Niederhofer, H., & Von Klitzing, K. (2012). Bright light treatment as mono-therapy of non-seasonal depression for 28 adolescents. *International Journal of Psychiatry in Clinical Practice*, *16*, 233–237.

Nizamie, S. H., & Tikka, S. K. (2014). Psychiatry and music. *Indian Journal of Psychiatry*, *56*, 128–140.

Noesselt, T., Tyll, S., Boehler, C. N., Budinger, E., Heinze, H. J., & Driver, J. (2010). Sound-induced enhancement of low-intensity vision: Multisensory influences on human sensory-specific cortices and thalamic bodies relate to perceptual enhancement of visual detection sensitivity. *The Journal of Neuroscience*, *30*, 13609–13623.

North, A. C. (2012). The effect of background music on the taste of wine. *British Journal of Psychology*, *103*, 293–301.

Norton, D. J., McBain, R. K., Pizzagalli, D. A., Cronin-Golomb, A., & Chen, Y. (2016). Dysregulation of visual motion inhibition in major depression. *Psychiatry Research*, *240*, 214–221.

Nugent, A., Farmer, C., Evans, J. W., Snider, S. L., Banerjee, D., & Zarate, C. A. (2019). Multimodal imaging reveals a complex pattern of dysfunction in corticolimbic pathways in major depressive disorder. *Human Brain Mapping*, *40*, 3940–3950.

O'Reardon, J. P., Solvason, H. B., Janicak, P. G., Sampson, S., Isenberg, K. E., Nahas, Z., McDonald, W. M., Avery, D., Fitzgerald, P. B., Loo, C., Demitrack, M. A., George, M. S., & Sackeim, H. A. (2007). Efficacy and safety of transcranial magnetic stimulation in the acute treatment of major depression: A multisite randomized controlled trial. *Biological Psychiatry*, *62*, 1208–1216.

Oren, D. A., Schwartz, P. J., Turner, E. H., & Rosenthal, N. E. (1995). Olfactory function in winter seasonal affective disorder. *The American Journal of Psychiatry*, *152*, 1531–1532.

Oren, D. A., & Terman, M. (1988). Tweaking the human circadian clock with light. *Science*, *279*, 396–399.

Osadchiy, V., Martin, C. R., & Mayer, E. A. (2020). Gut microbiome and modulation of CNS function. *Comprehensive Physiology*, *10*, 57–72.

Ouwens, M. A., Van Strien, T., & Van Leeuwe, J. F. (2009). Possible pathways between depression, emotional and external eating. A structural equation model. *Appetite*, *53*, 245–248.

Overby, L. A. 3rd, Harris, A. E., & Leek, M. R. (1989). Perceptual asymmetry in schizophrenia and affective disorder: Implications from a right hemisphere task. *Neuropsychologia*, *27*, 861–870.

Pabel, L. D., Hummel, T., Weidner, K., & Croy, I. (2018). The impact of severity, course and duration of depression on olfactory function. *Journal of Affective Disorders*, *238*, 194–203.

Pail, G., Huf, W., Pjrek, E., Winkler, D., Willeit, M., Praschak-Rieder, N., & Kasper, S. (2011). Bright-light therapy in the treatment of mood disorders. *Neuropsychobiology*, *64*, 152–162.

Park, D. H., Kripke, D. F., & Cole, R. J. (2007). More prominent reactivity in mood than activity and sleep induced by differential light exposure due to seasonal and local differences. *Chronobiology International*, *24*, 905–920.

Parker, G., Parker, I., & Brotchie, H. (2006). Mood state effects of chocolate. *Journal of Affective Disorders*, *92*, 149–159.

Partonen, T., & Lönnqvist, J. (2000). Bright light improves vitality and alleviates distress in healthy people. *Journal of Affective Disorders*, *57*, 55–61.

Pause, B. M., Miranda, A., Göder, R., Aldenhoff, J. B., & Ferstl, R. (2001). Reduced olfactory performance in patients with major depression. *Journal of Psychiatric Research*, *35*, 271–277.

Pause, B. M., Raack, N., Sojka, B., Göder, R., Aldenhoff, J. B., & Ferstl, R. (2003). Convergent and divergent effects of odors and emotions in depression. *Psychophysiology*, *40*, 209–225.

Penders, T. M., Stanciu, C. N., Schoemann, A. M., Ninan, P. T., Bloch, R., & Saeed, S. A. (2016). Bright light therapy as augmentation of pharmacotherapy for treatment of depression: A systematic review and meta-analysis. *The Primary Care Companion for CNS Disorders*, *18*, 10.

Penner-Goeke, S., & Binder, E. B. (2019). Epigenetics and depression. *Dialogues in Clinical Neuroscience*, *21*, 397.

Pignatiello, M. F., Camp, C. J., & Rasar, L. A. (1986). Musical mood induction: An alternative to the Velten technique. *Journal of Abnormal Psychology*, *95*, 295–297.

Pitsillou, E., Bresnehan, S. M., Kagarakis, E. A., Wijoyo, S. J., Liang, J., Hung, A., & Karagiannis, T. C. (2020). The cellular and molecular basis of major depressive disorder: Towards a unified model for understanding clinical depression. *Molecular Biology Reports*, *47*, 753–770.

Pjrek, E., Friedrich, M. E., Cambioli, L., Dold, M., Jager, F., Komorowski, A., Lanzenberger, R., Kasper, S., & Winkler, D. (2020). The efficacy of light therapy in the treatment of seasonal affective disorder: A meta-analysis of randomized controlled trials. *Psychotherapy and Psychosomatics*, *89*, 17–24.

Platte, P., Herbert, C., Pauli, P., & Breslin, P. A. (2013). Oral perceptions of fat and taste stimuli are modulated by affect and mood induction. *PLoS ONE*, *8*, e65006.

Pollatos, O., Kopietz, R., Linn, J., Albrecht, J., Sakar, V., Anzinger, A., Schandry, R., & Wiesmann, M. (2007). Emotional stimulation alters olfactory sensitivity and odor judgment. *Chemical Senses*, *32*, 583–589.

Pollock, R. A., Carter, A. S., Amir, N., & Marks, L. E. (2006). Anxiety sensitivity and auditory perception of heartbeat. *Behaviour Research and Therapy*, *44*, 1739–1756.

Postolache, T. T., Wehr, T. A., Doty, R. L., Sher, L., Turner, E. H., Bartko, J. J., & Rosenthal, N. E. (2002). Patients with seasonal affective disorder have lower odor detection thresholds than control subjects. *Archives of General Psychiatry*, *59*, 1119–1122.

Pulcu, E., & Elliott, R. (2015). Neural origins of psychosocial functioning impairments in major depression. *Lancet Psychiatry*, *2*, 835–843.

Qazi, J. J., Wilson, J. H., Payne, S. C., & Mattos, J. L. (2020). Association between smell, taste, and depression in nationally representative sample of older adults in the United States. *American Journal of Rhinology & Allergy*, *34*, 369–374.

Qi, T., Yang, Y., Yu, H., Fan, L., Luan, S., Zhang, L., Zhao, H., Lv, T., Jiang, T., & Song, X. (2020). Anatomical connectivity-based strategy for targeting transcranial magnetic stimulation as antidepressant therapy. *Frontiers in Psychiatry*, *11*, 1–8.

Rahe, C., Unrath, M., & Berger, K. (2014). Dietary patterns and the risk of depression in adults: A systematic review of observational studies. *European Journal of Nutrition*, *53*, 997–1013.

Ramos, M., Berrogain, C., Concha, J., Lomba, L., García, C. B., & Ribate, M. P. (2016). Pharmacogenetic studies: A tool to improve antidepressant therapy. *Drug Metabolism and Personalized Therapy*, *31*, 197–204.

Rehm, J., & Shield, K. D. (2019). Global burden of disease and the impact of mental and addictive disorders. *Current Psychiatry Reports*, *21*, 10.

Leigh, I. W., Robins, C. J., Welkowitz, J., & Bond, R. N. (1989). Toward greater understanding of depression in deaf individuals. *American Annals of the Deaf*, *134*, 249–254.

Rochet, M., El-Hage, W., Richa, S., Kazour, F., & Atanasova, B. (2018). Depression, olfaction, and quality of life: A mutual relationship. *Brain Sciences*, *8*, 80.

Rollin, H. R. (1998). Pioneers of music therapy. *Journal of Medical Biography*, *6*, 160–165.

Rolls, E. T. (2009). Functional neuroimaging of umami taste: What makes umami pleasant? *The American Journal of Clinical Nutrition*, *90*, 804S–813S.

Rose, N., Koperski, S., & Golomb, B. A. (2010). Mood food: Chocolate and depressive symptoms in a cross-sectional analysis. *Archives of Internal Medicine*, *170*, 699–703.

Rothenberg, D. O., & Zhang, L. (2019). Mechanisms underlying the anti-depressive effects of regular tea consumption. *Nutrients*, *11*, 1361.

Rottstaedt, F., Weidner, K., Strauss, T., Schellong, J., Kitzler, H., Wolff-Stephan, S., Hummel, T., & Croy, I. (2018). Size matters—The olfactory bulb as a marker for depression. *Journal of Affective Disorders*, *229*, 193–198.

Rovner, B. W., Casten, R. J., & Tasman, W. S. (2002). Effect of depression on vision function in age-related macular degeneration. *Archives of Ophthalmology*, *120*, 1041–1044.

Rovner, B. W., & Shmuely-Dulitzki, Y. (1997). Screening for depression in low-vision elderly. *International Journal of Geriatric Psychiatry*, *12*, 955–959.

Sachs, M. E., Damasio, A., & Habibi, A. (2015). The pleasures of sad music: A systematic review. *Frontiers in Human Neuroscience*, *9*, 404.

Sackeim, H. A. (2000). Repetitive transcranial magnetic stimulation: What are the next steps? *Biological Psychiatry*, *48*, 959–961.

Sanacora, G., Treccani, G., & Popoli, M. (2012). Towards a glutamate hypothesis of depression: An emerging frontier of neuropsychopharmacology for mood disorders. *Neuropharmacology*, *62*, 63–77.

Sanchez-Villegas, A., Zazpe, I., Santiago, S., Perez-Cornago, A., Martinez-Gonzalez, M. A., & Lahortiga-Ramos, F. (2018). Added sugars and sugar-sweetened beverage consumption, dietary carbohydrate index and depression risk in the Seguimiento Universidad de Navarra (SUN) Project. *The British Journal of Nutrition*, *119*, 211–221.

Satoh, M., Nagata, K., & Tomimoto, H. (2015). Sound richness of music might be mediated by color perception: A PET study. *Behavioural Neurology*, *2015*, 241804.

Savic, I. (2001). Processing of odorous signals in humans. *Brain Research Bulletin*, *54*, 307–312.

Schiffman, S. S. (1983). Taste and smell in disease (first of two parts). *The New England Journal of Medicine*, *308*, 1275–1279.

Schiffman, S. S., Zervakis, J., Suggs, M. S., Budd, K. C., & Iuga, L. (2000). Effect of tricyclic antidepressants on taste responses in humans and gerbils. *Pharmacology, Biochemistry, and Behavior*, *65*, 599–609.

Schiffman, S. S., Zervakis, J., Suggs, M. S., Shaio, E., & Sattely-Miller, E. A. (1999). Effect of medications on taste: Example of amitriptyline HCl. *Physiology & Behavior*, *66*, 183–191.

Schlipf, S., Batra, A., Walter, G., Zeep, C., Wildgruber, D., Fallgatter, A. J., & Ethofer, T. (2013). Judgment of emotional information expressed by prosody and semantics in patients with unipolar depression. *Frontiers in Psychology*, *4*, 461.

Schroeder, C. E., & Foxe, J. (2005). Multisensory contributions to low-level, 'unisensory' processing. *Current Opinion in Neurobiology*, *15*, 454–458.

Seggie, J., Canny, C., Mai, F., McCrank, E., & Waring, E. (1989). Antidepressant medication reverses increased sensitivity to light in depression: Preliminary report. *Progress in Neuro-Psychopharmacology & Biological Psychiatry*, *13*, 537–541.

Seo, H. S., Roidl, E., Müller, F., & Negoias, S. (2010). Odors enhance visual attention to congruent objects. *Appetite*, *54*, 544–549.

Serafini, G., Gonda, X., Canepa, G., Pompili, M., Rihmer, Z., Amore, M., & Engel-Yeger, B. (2017). Extreme sensory processing patterns show a complex association with depression, and impulsivity, alexithymia, and hopelessness. *Journal of Affective Disorders*, *210*, 249–257.

Serby, M., Larson, P., & Kalkstein, D. (1990). Olfactory sense in psychoses. *Biological Psychiatry*, *28*, 830.

Shams, L., Kamitani, Y., & Shimojo, S. (2000). What you see is what you hear. *Nature*, *408*, 788.

Shmuely-Dulitzki, Y., & Rovner, B. W. (1997). Screening for depression in older persons with low vision. Somatic eye symptoms and the geriatric depression scale. *The American Journal of Geriatric Psychiatry*, *5*, 216–220.

Siegel, E. H., & Stefanucci, J. K. (2011). A little bit louder now: Negative affect increases perceived loudness. *Emotion*, *11*, 1006–1011.

Singh, A., Erwin-Grabner, T., Goya-Maldonado, R., & Antal, A. (2020). Transcranial magnetic and direct current stimulation in the treatment of depression: Basic mechanisms and challenges of two commonly used brain stimulation methods in interventional psychiatry. *Neuropsychobiology*, *79*(6), 397–406. https://doi.org/10.1159/000502149

Smith, J. L., & Noon, J. (1998). Objective measurement of mood change induced by contemporary music. *Journal of Psychiatric and Mental Health Nursing*, *5*, 403–408.

Spence, C. (2019). On the relationship(s) between color and taste/flavor. *Experimental Psychology*, *66*, 99–111.

Stansfield, S. A. (1992). Noise, noise sensitivity and psychiatric disorder: Epidemiological and psychophysiological studies. *Psychological Medicine*, *22*, 1–44.

Steinberg, G., Lipton, D. S., Eckhardt, E. A., Goldstein, M., & Sullivan, J. (1998). The diagnostic interview schedule for deaf patients on interactive video: A preliminary investigastion. *The American Journal of Psychiatry*, *155*, 1603–1604.

Steiner, J. E., Lidar-Lifschitz, D., & Perl, E. (1993). Taste and odor: Reactivity in depressive disorders, a multidisciplinary approach. *Perceptual and Motor Skills*, *77*, 1331–1346.

Steiner, J. E., Rosenthal-Zifroni, A., & Edelstein, E. L. (1969). Taste perception in depressive illness. *The Israel Journal of Psychiatry and Related Sciences*, *7*, 223–232.

Stephens, S. D., & Halam, R. S. (1985). The Crown-Crisp experimental index in patients complaining of tinnitus. *British Journal of Audiology*, *19*, 151–158.

Strain, J. J. (2018). The psychobiology of stress, depression, adjustment disorders and resilience. *The World Journal of Biological Psychiatry*, *19*:(sup1), S14–S20.

Sullivan, M. D., Katon, W., & Dobie, R. (1988). Disabling tinnitus: Association with affective disorder. *General Hospital Psychiatry*, *10*, 285–291.

Taalman, H., Wallace, C., & Milev, R. (2017). Olfactory functioning and depression: A systematic review. *Frontiers in Psychiatry*, *8*, 190.

Teichert, M., & Bolz, J. (2018). How senses work together: Cross-modal interactions between primary sensory cortices. *Neural Plasticity*, 5380921.

Thompson, W. F., Schellenberg, E. G., & Husain, G. (2001). Arousal, mood, and the Mozart effect. *Psychological Science*, *12*, 248–251.

Tivadar, R. I., Retsa, C., Turoman, N., Matusz, P. J., & Murray, M. M. (2018). Sounds enhance visual completion processes. *NeuroImage*, *179*, 480–488.

Tollkötter, M., Pfleiderer, B., Sörös, P., & Michael, N. (2006). Effects of antidepressive therapy on auditory processing in severely depressed patients: A combined MRS and MEG study. *Journal of Psychiatric Research*, *40*, 293–306.

Tornek, A., Field, T., Hernandez-Reif, M., Diego, M., & Jones, N. (2003). Music effects on EEG in intrusive and withdrawn mothers with depressive symptoms. *Psychiatry*, *66*, 234–243.

Trivedi, M. H., Rush, A. J., Wisniewski, S. R., Nierenberg, A. A., Warden, D., Ritz, L., Norquist, G., Howland, R. H., Lebowitz, B., McGrath, P. J., Shores-Wilson, K., Biggs, M. M., Balasubramani, G. K., Fava, M., & STAR*D Study Team. (2006). Evaluation of outcomes with citalopram for depression using measurement-based care in STAR*D: Implications for clinical practice. *The American Journal of Psychiatry*, *163*, 28–40.

Blazer, D. G., & Tucci, D. L. (2019). Hearing loss and psychiatric disorders: A review. *Psychological Medicine*, *49*, 891–897.

Uekermann, J., Abdel-Hamid, M., Lehmkämper, C., Vollmoeller, W., & Daum, I. (2008). Perception of affective prosody in major depression: A link to executive functions? *Journal of the International Neuropsychological Society*, *14*, 552–561.

Unal, G., & Canbeyli, R. (2019). Psychomotor retardation in depression: A critical measure of the forced swim test. *Behavioural Brain Research*, *372*, 112047.

Van Beilen, M., Bult, H., Renken, R., Stieger, M., Thumfart, S., Cornelissen, F., & Kooijman, V. (2011). Effects of visual priming on taste-odor interaction. *PLoS ONE*, *6*, e23857.

Vandewalle, G., Schwartz, S., Grandjean, D., Wuillaume, C., Balteau, E., Degueldre, C., Schabus, M., Phillips, C., Luxen, A., Dijk, D. J., & Maquet, P. (2010). Spectral quality of light modulates emotional brain responses in humans. *PNAS*, *107*, 19549–19554.

Vermeulen, E., Stronks, K., Snijder, M. B., Schene, A. H., Lok, A., de Vries, J. H., Visser, M., Brouwer, I. A., & Nicolaou, M. (2017). A combined high-sugar and high-saturated-fat dietary pattern is associated with more depressive symptoms in a multi-ethnic population: The HELIUS (Healthy Life in an Urban Setting) study. *Public Health Nutrition*, *20*, 2374–2382.

Villas Boas, G. R., Boerngen de Lacerda, R., Paes, M. M., Gubert, P., Almeida, W., Rescia, V. C., de Carvalho, P., de Carvalho, A., & Oesterreich, S. A. (2019). Molecular aspects of depression: A review from neurobiology to treatment. *European Journal of Pharmacology*, *851*, 99–121.

Vincis, R., & Fontanini, A. (2019). Central taste anatomy and physiology. *Handbook of Clinical Neurology*, *164*, 187–204.

Vuilleumier, P. (2015). Affective and motivational control of vision. *Current Opinion in Neurology*, *28*, 29–35.

Wallace, M. T., Ramachandran, R., & Stein, B. E. (2004). A revised view of sensory cortical parcellation. *PNAS*, *101*, 2167–2172.

Wang, J., Nicol, T., Skoe, E., Sams, M., & Kraus, N. (2009). Emotion modulates early auditory response to speech. *Journal of Cognitive Neuroscience*, *21*, 2121–2128.

Watanabe, K., & Shimojo, S. (2001). When sound affects vision: Effects of auditory grouping on visual motion perception. *Psychological Science*, *12*, 109–116.

Watt, J. D., & Davis, F. E. (1991). The prevalence of boredom proneness and depression among profoundly deaf residential school adolescents. *American Annals of the Deaf*, *136*, 409–413.

Weber, S. T., & Heuberger, E. (2008). The impact of natural odors on affective states in humans. *Chemical Senses*, *33*, 441–447.

Welge-Lüssen, A., Drago, J., Wolfensberger, M., & Hummel, T. (2005). Gustatory stimulation influences the processing of intranasal stimuli. *Brain Research*, *1038*, 69–75.

WHO. (2016). *Preventing Depression in the WHO European Region*. World Helth Organization. Available 0nline:https://www.euro.who.int/en/healthtopics/noncommunicable-diseases/mental-health/publications/2016/preventing-depression-in-the-whoeuropean-region-2016

WHO. (2018). *Depression*. World Health Organization. Available online: https://www.who.int/news-room/fact-sheets/detail/depression

Winter, G., Hart, R. A., Charlesworth, R., & Sharpley, C. F. (2018). Gut microbiome and depression: What we know and what we need to know. *Reviews in the Neurosciences*, *29*, 629–643.

Wolniczak, I., Cáceres-DelAguila, J. A., Maguiña, J. L., & Bernabe-Ortiz, A. (2017). Fruits and vegetables consumption and depressive symptoms: A population-based study in Peru. *PLoS ONE*, *12*, e0186379.

World Health Organization, Executive board 130th session (2012). Global burden of mental disorders and the need for a comprehensive, coordinated response from health and social workers at the country level: Report by the Secretariat.

World Health Organization. (2017). *Depression and Other Common Mental Disorders: Global Health Estimates: World Health Organization*. Geneva, Switzerland.

Yan, K. S., & Dando, R. (2015). A crossmodal role for audition in taste perception. *Journal of Experimental Psychology. Human Perception and Performance*, *41*, 590–596.

Yang, Z., Li, J., Gui, X., Shi, X., Bao, Z., Han, H., & Li, M. D. (2020). Updated review of research on the gut microbiota and their relation to depression in animals and human beings. *Molecular Psychiatry*, *25*(11), 2579–2772. https://doi.org/10.1038/s41380-020-0729-1

Yovell, Y., Sackeim, H. A., Epstein, D. G., Prudic, J., Devanand, D. P., McElhiney, M. C., Settembrino, J. M., & Bruder, G. E. (1995). Hearing loss and asymmetry in major depression. *The Journal of Neuropsychiatry and Clinical Neurosciences*, *7*, 82–89.

Zald, D. H., & Pardo, J. V. (1997). Emotion, olfaction, and the human amygdala: Amygdala activation during aversive olfactory stimulation. *PNAS*, *94*, 4119–4124.

Zald, D. H., & Pardo, J. V. (2000). Functional neuroimaging of the olfactory system in humans. *International Journal of Psychophysiology*, *36*, 165–181.

Zazove, P., Meador, H. E., Aikens, J. E., Nease, D. E., & Gorenflo, D. W. (2006). Assessment of depressive symptoms in deaf persons. *Journal of American Board of Family Medicine*, *19*, 141–147.

Zellner, D. A., & Kautz, M. A. (1990). Color affects perceived odor intensity. *Journal of Experimental Psychology*, *16*, 391–397.

Zellner, D. A., & Whitten, L. A. (1999). The effect of color intensity and appropriateness on color-induced odor enhancement. *The American Journal of Psychology*, *112*, 585–604.

Zhao, K., Bai, Z. G., Bo, A., & Chi, I. (2016). A systematic review and meta-analysis of music therapy for the older adults with depression. *International Journal of Geriatric Psychiatry*, *31*, 1188–1198.

Zheng, P., Zeng, B., Zhou, C., Liu, M., Fang, Z., Xu, X., Zeng, L., Chen, J., Fan, S., Du, X., Zhang, X., Yang, D., Yang, Y., Meng, H., Li, W., Melgiri, N. D., Licinio, J., Wei, H., & Xie, P. (2016). Gut microbiome remodeling induces depressive-like behaviors through a pathway mediated by the host's metabolism. *Molecular Psychiatry*, *21*, 786–796.

Zhou, L., Ohata, M., & Arihara, K. (2016). Effects of odor generated from the glycine/glucose Maillard reaction on human mood and brainwaves. *Food & Function*, *7*, 2574–2581.

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