Links between Musicality and Vocal Emotion Perception

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Abstract

Links between musicality and vocal emotion perception skills have only recently emerged as a focus of study. Here we review current evidence for or against such links. Based on a systematic literature search, we identified 33 studies that addressed either (1) vocal emotion perception in musicians and non-musicians, (2) effects of musical training intervention on vocal emotion perception, (3) potentials of musical training for cochlear implant users, (4) vocal emotion perception in individuals with congenital amusia, or (5) the role of individual differences (e.g., musical interests, psychoacoustic abilities). Overall, the evidence supports a link between musicality and vocal emotion perception abilities. We discuss potential underlying factors, including origins of musicality in nature and nurture.

Keywords

Vocal emotion perception, musicality, musical training, amusia

Introduction and Review of Related Literature

Human social communication depends on the exchange and mutual representation of multiple social signals. Among these, vocally expressed emotions are fundamental to human interaction (Grandjean, 2020; Sauter, 2017; Scherer, 1986; Scherer et al., 2016; A. W. Young et al., 2020). For several decades, this field was dominated by the view that humans perceive emotions efficiently and automatically. More recently however, prominent interindividual differences in vocal emotion perception skills became a focus of attention (Mill et al., 2009; Schirmer et al., 2005). For humans, voices and music are both prominent means of auditory communication of emotions. Some researchers have emphasized the similarities in the acoustic features of certain emotions in the voice and in music (Juslin & Laukka, 2003; Scherer, 1995), whereas others reported similarities in the neural circuits involved in recognizing basic emotions from music as compared to voices (Aubé et al., 2015). Accordingly, differences in vocal emotion perception skills could be associated with different levels of musicality. Music forms a central part of human culture, and appreciation of music is interconnected with intense emotional experiences (Schäfer et al., 2013). However, there is huge variation in terms of musical aptitude and musical training. Here we integrate the currently available research that assessed possible links between musicality - in terms of both aptitude and training effects - and vocal emotion perception.

This review adds vocal emotion perception to several previous integrative works that discussed the association of musical training with other non-musical abilities. Compared to non-musical peers, musicians show superior pitch, temporal and timbre processing (Kraus & Chandrasekaran, 2010) and those advantages expand from the musical into the vocal domain (Chartrand et al., 2008). Beyond the auditory modality, musicians have better audiovisual and auditory-motor integration, working memory, spatial abilities, executive functioning, general intelligence as well as speech and language skills (Elmer et al., 2018; Schellenberg, 2001, 2016). At the brain level, musicality is associated with widespread functional and structural differences, such as larger grey matter volume and stronger

connectivity between areas associated with auditory, motor and visuospatial functions (Kraus & Chandrasekaran, 2010; Pantev & Herholz, 2011). Against this background of established links between musicality and comparatively distant competencies, the field remarkably lacks systematic integration of evidence concerning the related domain of voices, and vocal emotion perception in particular.

Given the abovementioned benefits of musicality, a link between musicality and vocal emotion perception seems plausible. We considered that individual musicality may be determined by a combination of genetic (“talent”) and environmental factors (“training”), the contributions of which can be difficult to determine. Similarly, underlying mechanisms for the link between musicality and vocal emotion could be determined by both nature and nurture factors. On the nature side, some people might have an innate capacity to perceive fine-grained acoustic structures of both musical and vocal sounds, alongside with an inner drive to engage in musical activities. Accordingly, musical and vocal emotional capacities would be linked through genetic factors. This view is in line with Darwin's “protolanguage hypothesis”, claiming that music and speech both evolved from the same origin, a musical protolanguage comprised of rudimental vocalizations (Darwin, 1871; Thompson et al., 2012), in which the expression of vocal emotions was a key aspect of communication (Fitch, 2013). Indeed, expression of emotion in music and vocal channels seem to be based on similar acoustic cues, supporting the idea that emotional communication in both channels are intertwined (Juslin & Laukka, 2003). This gives rise to the possibility that capacities in both channels are driven by the same underlying genetic factors and that there are innate forces that create transfer between musical and vocal capacities.

On the nurture side, it is assumed that musical training causes the differences that are observed in musicians and non-musicians. From this perspective, the acoustic similarity between music and vocal emotions might be a reason for why extensive training in the musical domain can lead to an improvement in vocal emotion perception. A more elaborated nurture-based approach is offered by

the OPERA hypothesis (Patel, 2011). Although it was originally developed to explain music-to-speech transfer effects, it can also be considered in the context of vocal emotion perception. The OPERA hypothesis states that musical-training benefits in other domains only occur when five conditions are met: (1) **O**verlap, (2) **P**recision, (3) **E**motion, (4) **R**epetition and (5) **A**ttention. *Overlap* refers to shared neural networks between music and vocal emotion processing. Indeed, neuroimaging data suggest common neural networks for the processing of emotional sounds, including vocal, musical and environmental sources (Escoffier et al., 2013; Fröhholz et al., 2014; Fröhholz et al., 2016; Grandjean, 2020; Schirmer et al., 2012). Core structures include the auditory cortex, the superior temporal cortex, frontal regions, the insula, the amygdala, the basal ganglia, and the cerebellum (Fröhholz et al., 2016). *Precision* refers to the high auditory-motor demands that musical training places on these shared networks. The third condition, *emotion*, claims that the musical activity has to be perceived as rewarding. The subjective feeling of highly pleasurable experiences such as “chills”, or “shivers-down-the-spine” are among the main reasons for why humans engage in musical activities, and those experiences are associated with brain activity changes in regions involved in reward, emotion, and arousal – including the amygdala, the ventral striatum, midbrain structures, orbitofrontal and ventromedial prefrontal areas (Blood & Zatorre, 2001; Stewart et al., 2006). Finally, the necessities of *repetition* and *attention* stress the point that training-induced benefits depend critically on how frequently and focused musical activity is pursued over time. It may take years of active musical engagement to observe stable differences in musicians’ brains (Kraus & White-Schwoch, 2017), which can be regarded as truly reflecting training-induced changes (Elbert et al., 1995; Kraus & Chandrasekaran, 2010; Pantev & Herholz, 2011).

As it stands, the link of musicality with vocal emotion perception received relatively little attention and is poorly understood. This seems surprising, given that adequate emotion perception is crucial for wellbeing and perceived quality of life (Phillips et al., 2010; Schorr et al., 2009). However, to the best of our knowledge, there has been no attempt so far to integrate the existing evidence in a systematic manner. In this review, we aim at closing this gap, while including the full range of musical

abilities: We survey findings from highly trained musicians, but also from people with exceptionally poor musical abilities. Finally, we include studies on cochlear implant (CI) users, who have significant difficulty recognizing vocal emotions due to degraded auditory input (Jiam et al., 2017), which might be improved with music-based interventions (Paquette et al., 2018).

Systematic Literature Search / Inclusion Criteria

We conducted parallel literature searches on Web of Science, PubMed, and PsychInfo on March 19, 2020, using the search terms “(voice OR prosody) AND (emotion* OR affect*) AND (music* OR auditory expert* OR amusi* OR auditory training)”. We restricted publication language to English and considered empirical studies only. In total, the initial search returned 1723 articles (Web of Science N = 755, PubMed N = 405 and PsychInfo N = 563), to which we applied the following inclusion criteria: (1) vocal emotion perception was assessed as dependent variable, (2) musicality was assessed, manipulated, or used as a defining criterion for a group-based comparison, and (3) responses were measured on the behavioral or the brain level. We also screened the reference lists of the identified articles for relevant publications. This selection procedure resulted in a total of 33 articles, which we review below. For a summary, please refer to Table 1. When screening the relevant literature, we noted that a substantial proportion (27/33, or 82%) of identified papers were published in 2011 or later, reflecting the current attention to this topic that contributed to motivating our present review.

[Insert Table 1 about here, please]

Review of Identified Literature

Differences in Vocal Emotion Perception between Musicians and Non-musicians

Behavioral Data

The presumably first study comparing vocal prosody perception in musicians and non-musicians comes from Nilsonne and Sundberg (1985). They presented pairs of fundamental frequency contours extracted from patients’ voices while reading text either during depression or after recovery.

Listeners were music and law students. Music students made significantly fewer errors than law students when judging which sample was recorded during depression. This study could be considered as first evidence for a musician effect on vocal emotion recognition, although depression obviously relates to more enduring affective states, relative to the more dynamic states typically communicated in emotional prosody as addressed in the studies below. These findings were replicated by Thompson et al. (2004). Musically trained participants performed better than untrained participants in categorizing emotional tone sequences extracted from vocal utterances. In a second Experiment however, which included additional sentences in familiar and unfamiliar languages, their effects were less straightforward: musicians' performance was better for sad, fearful, and neutral, but not for happy and angry prosody. As a caveat, musical training was associated with differences in cognitive abilities too, limiting conclusions from this study. This issue was addressed by Lima and Castro (2011), who compared highly trained musicians with non-musicians in two age groups (18–30 years and 40–60 years). Musicians outperformed their non-musical peers, similarly across emotions and age groups, even when effects were controlled for cognitive differences. Further, similar patterns of misattributions and acoustic cue utilization were observed in both groups, suggesting that group differences were of a quantitative rather than a qualitative nature.

Dmitrieva et al. (2006) tested vocal emotion perception by musicians and controls in children of three age groups (7–10, 11–13, and 14–17 years). Musicians outperformed their non-musical peers, but this effect was mainly driven by the youngest group. This finding could indicate either that the limited musical experience in very young children allowed innate aptitude to be more visible; or that musical experience might promote an earlier development of emotion sensitivity. Başkent et al. (2018) also studied adolescent musicians and non-musicians. Their work was motivated by Fuller et al. (2014), who conducted a similar design with adults. Both studies compared emotion recognition performance of unprocessed and degraded speech intended to reproduce the spectro-temporal degradation experienced by CI users (Başkent et al., 2018). Whereas Fuller et al. (2014) found a small musician advantage in both conditions, Başkent et al. (2018) did not, potentially due to limited test-

power with a much smaller sample compared to Fuller et al. (2014). Statistical comparison of both experiments revealed significant age effects, suggesting a maturation of the auditory system during emerging adulthood (Başkent et al., 2018).

Sensitivity to vocal prosody is of particular relevance in parent-infant interactions, where parents' adequate behavior crucially depends on their capacity to infer the infants' needs from the sound of their cries. Parsons et al. (2014) investigated sensitivity to distressed infants' cries in parents and non-parents. In parents, years of musical training was positively correlated with sensitivity to infant distress. Accordingly, musicality could foster a positive parent-child interaction due to enhanced sensitivity to the infants' emotional state. K. S. Young et al. (2012) used the same paradigm on musicians and non-musicians with and without depression. Musicians with depression performed comparable to non-depressed participants (with or without musical training) and significantly better than non-musicians with depression. Thus, musicality can potentially protect against compromised auditory sensitivity towards the infant during a depression period.

Several studies raised the question whether emotional sensitivity in musicians is restricted to the auditory domain. Twaite (2016) compared performance of musicians and non-musicians for prosodic, lexical, facial, and musical emotions and reported a musician advantage for the prosodic and the musical channel. No differences were observed for facial or lexical emotions, indicating that the musicians' advantage was limited to the auditory modality. However, Weijkamp and Sadakata (2017) reported somewhat conflicting results. They tested emotion recognition of musicians and non-musicians in single-modality auditory and visual tasks, using voices and faces, as well as in an emotional Stroop task. No group differences were seen in the unimodal tasks, but musicians performed better in audiovisual tasks, which might point towards more efficient cross-modal integration.

Up to now, most studies comparing musicians and non-musicians support the hypothesis that musicians have an advantage in vocal emotion perception. This advantage seems to be of a quantitative rather than a qualitative nature (Lima & Castro, 2011; Twaite, 2016). However, the degree to which this advantage is moderated by factors such as innate musicality, the amount of musical training, age at training onset, or maturation of the auditory system all remain subjects for future research.

Brain Data

A small number of studies investigated differences between musicians and non-musicians with respect to the brain basis of vocal emotional processing. Strait et al. (2009) recorded brainstem potentials evoked by acoustically simple and complex portions of an infant's cry, and reported an intriguing interaction between musical expertise and stimulus complexity: Compared to controls, musicians showed reduced responses in the simple, but increased responses in the complex portion of the sound. The authors interpret these findings as indicating that (1) musical expertise results in fine neural tuning to acoustic features that are important to vocal communication, and (2) subcortical mechanisms contribute to vocal emotion perception. Further, different outcome measures in the brainstem signal suggested that the duration of musical training predicts temporal precision, whereas age at training onset was associated with fundamental frequency and timbre cues.

Using functional magnetic resonance imaging (fMRI), Park et al. (2015) compared brain activations of musicians and non-musicians to happy, sad, fearful, and neutral vocalizations. For sad stimuli only, musicians showed increased activation in the middle frontal gyrus, the anterior medial prefrontal cortex, the posterior cingulate cortex, and the retrosplenial cortex. The authors hypothesized that sadness might be of "higher affective saliency" for musicians.

Three electroencephalography (EEG) studies investigated how different cortical processing stages of vocal emotions differ as a function of musical expertise. Pinheiro et al. (2015) and Rigoulot et al.

(2015) recorded event-related potentials (ERPs) and found that modulatory effects of musical expertise can be observed in early stages of cortical processing before 100 ms (P50, N100), as well as in later stages (P200). Nolden et al. (2017) re-analyzed the data of Rigoulot et al. (2015) with focus on induced oscillatory activity and found larger induced power for musicians in the theta (4-8 HZ) and the alpha-band (8-12 HZ).

Taken together, the existing work on brainstem potentials and EEG suggest that modulatory effects of musicality can be observed in very early processing steps of vocal emotions, which are associated with a basic analysis of auditory cues and allocation of emotional significance (Schirmer & Kotz, 2006). Neuroimaging complements this by implicating brain regions associated with higher order functions. Overall, neuroscientific research on links between musicality and vocal emotion perception is still in its infancy, although it clearly has potential to shed light on the underlying mechanisms of musicians' enhanced ability to process vocal emotions.

Effects of Musical Training Interventions on Vocal Emotion Perception

Apart from comparing musicians and non-musicians, the effectiveness of musical interventions was at the focus of several studies, reviewed in this section. Note that designs with randomized assignments to intervention and control conditions are particularly valuable in the context of the nature-nurture debate, as they permit to deconfound training effects from self-selection effects when seeking musical education.

Intervention-based Studies in Normal Hearing Individuals

Thompson et al. (2004) randomly assigned six-year-old children to one year of training in keyboard, singing, drama, or no-lesson. Post-intervention, the drama and keyboard groups outperformed the no-lesson group in vocal emotion perception. Perhaps surprisingly, this effect was not found in the singing group. Thompson et al. (2004) speculated that singing may have trained vocal production of

pitch contours that conflict with natural prosodic use of the voice. Nashkoff (2007) reported that simple pitch discrimination training alone can improve speech prosody decoding skills, but only for already highly trained musicians. Another attempt to show the effectiveness of musical intervention was made by Mualem and Lavidor (2015) who assigned participants either to music-based or visual-art-based interventions, which focused explicitly on expression of emotions in the respective domain. After only four sessions, an improvement of vocal emotion recognition performance was observed in the music compared to the art group. However, when both groups were compared to a group of highly trained musicians, no performance differences were found. This could suggest that the effectiveness of the intervention partially reflected “training to the test”, as the intervention explicitly focused on emotions. Finally, Bodner et al. (2012) reported that a music-based intervention improved recognition of happiness in patients with social anxiety disorder (SAD) who often display a persistent bias towards negative emotions. Although these findings need further verification, they suggest that perceptual biases in affective disorders may be attenuated by musical interventions. Together, the body of literature on interventions is still sparse for the normal hearing population, whereas musical trainings/interventions have been studied more intensely in the field of hearing rehabilitation for cochlear implant users.

Intervention-based Studies in Cochlear Implant Users

All studies reviewed in this section included vocal emotion perception as a part of larger test batteries to assess musical training effects on voice, speech and music perception in cochlear implant (CI) users. Petersen et al. (2012) recruited CI users within 14 days after implantation. Half of them received a six-month musical ear training. While distinct improvements were observed for musical perception, the pattern was less clear for vocal emotions: the intervention group showed an earlier onset of improvement, but the endpoints were comparable. However, the freshly implanted CI users in this study were in speech therapy during the intervention, which could have interfered with the musical training. In contrast, Fuller et al. (2018) studied adult CI users with a minimum of one year

post implantation, who were randomly assigned to either (1) a pitch-timbre group that received receptive training, (2) a music-therapy group with face-to-face sessions including active music production, or (3) a control group with non-musical activities; over a period of six weeks. Crucially, vocal emotion recognition improved only in the music-therapy group, emphasizing the importance of active musical engagement and/or social interaction for training success. Similarly, Chari et al. (2020) also studied adult CI users with at least one year of implant experience and assigned them to auditory-motor, auditory-only, or no training, over a period of three months. However, there was no effect on vocal emotion perception, even though the intervention period was about twice as long as in Fuller et al. (2018). Notably, both studies used very small sample sizes with less than 10 observations per group. While findings are intriguing and potentially important, they call for further exploration and replication with more powerful designs, particularly when effect sizes and statistical power are not (yet) routinely reported.

Only one study investigated the role of musical training in children with CIs, aged 6 and 15 years (Good et al., 2017). Improvements in vocal emotion perception were found after six months of piano lessons compared to a visual art training. The authors concluded that musical training might be an effective supplement for auditory rehabilitation in children. In addition to intervention-based approaches, Waaramaa et al. (2018) showed that self-reported musical interests - especially a preference for dancing - predicted vocal emotion perception capacity in CI users. Taken together, findings emphasize an importance of active musical engagement, as compared to pure receptive training, in order to promote recovery of emotion perception after cochlear implantation.

Impairments of Vocal Emotion Perception in Individuals with Congenital Amusia

To gain a fuller understanding of the association between musicality and vocal emotion perception, it is also worthwhile to study individuals with exceptionally poor musical abilities, such as in *congenital amusia*. Individuals with *congenital amusia* display a perceptual disorder specific to the musical

domain, in the presence of normal hearing and otherwise intact cognition (Ayotte et al., 2002; Stewart et al., 2006). Congenital amusia is usually measured using *the Montreal Battery of Evaluation of Amusia* (MBEA, Peretz et al., 2003). Thompson et al. (2012) were the first to show poorer vocal prosody recognition in participants with amusia compared to controls and further observed a certain degree of awareness of their perceptual limitations in daily life. Lolli et al. (2015) suggested that a core problem could be poor pitch (F0) perception: although participants with suspected amusia performed similar to controls for emotion perception from unfiltered or high-pass filtered (4800Hz) utterances, they performed poorer in low-pass filtered (500Hz) utterances which presumably degraded timbre while preserving pitch contour information. Corroborating a selective deficit in pitch perception, Pralus et al. (2019) found that controls and participants with amusia exhibited comparable emotion recognition for whole sentences, but participants with amusia performed worse for vowels. Of relevance, perceived emotional intensity was comparable in both groups for all stimuli, which was interpreted as preserved implicit processing of emotional prosody in amusia.

Lima et al. (2016) took a crossmodal approach; in two experiments they tested adults with amusia and matched controls on their ability to identify emotions in different types of vocal stimuli and silent facial expressions. Participants with amusia were found to be impaired in the auditory and the visual domain, implying more universal emotion processing difficulties, potentially in line with an insightful analysis of patterns of category-specific but multimodal emotion recognition deficits that may also be characteristic of neuropsychological patients (A. W. Young, 2018). Zhang et al. (2018) and Cheung et al. (2020) were interested in relationships between amusia and emotional prosody processing in tonal languages. Zhang et al. (2018) tested participants from a Mandarin-speaking background with unfiltered and low-pass filtered speech (500 Hz). Unlike Lolli et al. (2015), participants with amusia were found to be worse for both filtered and unfiltered speech, disconfirming the hypothesis that tonal language acquisition might compensate for pitch-processing deficits in participants with amusia. For unfiltered speech, Cheung et al. (2020) reported similar findings in Cantonese speakers with amusia. Taken together, published findings on amusia paint a

fairly consistent picture, suggesting that musical impairments transfer to vocal emotion perception, and that impairments for vocal emotions may originate from poor pitch perception.

Correlation of Vocal Emotion Perception with Musical Interests or Psychoacoustic Abilities

Complementing studies on extreme groups, other researchers measured normal interindividual variation of musicality in the general population to link it to variability in vocal emotion perception. The most compelling evidence against this link was provided by Trimmer and Cuddy (2008). Their correlational analysis for 100 participants revealed that musicality, as assessed via MBEA scores, was not associated with vocal emotion perception, a finding that they replicated with another 92 participants. Trimmer and Cuddy (2008) concluded that emotion perception in music and the voice is not linked via auditory sensitivity but rather via a supramodal emotional processor. This finding conflicts with many results discussed above and provoked large debates in the field. For instance, Lima and Castro (2011) argued that the participants in the study had only 6.5 years musical training on average, which might have been insufficient to observe a significant effect. However, Dibben et al. (2018) also failed to observe a relationship between musical interests and moment-to-moment reports of perceived emotion in longer (2-3 min) vocal excerpts. As a limitation, musical interests were assessed with a single dichotomous item in this study, which hardly captured fine grained interindividual variation of musicality.

Other studies reported positive correlations. Globerson et al. (2013) did not assess full-scale musical ability, but psychoacoustic measures of pitch-discrimination were found to predict vocal emotion perception performance. This highlights the importance of subtle pitch variations for emotional prosody perception, in line with the impairments in amusia discussed in the previous section. Finally, Waaramaa and Leisiö (2013) investigated the link between musical interests and emotional prosody perception in a large-scale cross-cultural study across five different countries (Estonia, Finland, Russia, Sweden, USA). Musical interests tended to have a positive effect on vocal emotion

identification, but like in Dibben et al. (2018), this finding was based on very few self-reported items only.

In summary, correlational studies on the link between musicality and vocal emotion perception yielded conflicting results. This could be due to the substantial differences in assessing musicality, ranging from musical tests to short questionnaires. Indeed, the use of standardized and validated instruments for the assessment of musical interests is desirable, as this should promote better comparability across future studies, and contribute to resolving remaining controversies.

Discussion

While the transfer of musicality to speech perception abilities is well documented, the transfer to emotion perception attracted substantial scientific interest only recently. Overall, associations between musicality and vocal emotion perception ranged from strongly positive to absent, with the majority of studies supporting the idea that musicality is associated with better vocal emotion perception capacities. In the following, we will first discuss how these studies inform us about the contribution of nature and nurture factors for this link. Second, we will evaluate the effectiveness of active versus receptive musical training, and the moderating role of different acoustic cues signaling emotionality in both music and the voice. Finally, we will identify some relevant questions for further research.

Nature and Nurture

Musicality in people emerges from a combination of genetic and environmental factors. Likewise, the observed link between musicality and vocally expressed emotions could be either explained by a dispositional sensitivity to the musical and the vocal channel; or by a transfer from musical training effects into the vocal domain. Additionally, conditions of nature and nurture interact in individuals, making it difficult to estimate the degree of their respective contributions. Unfortunately, apart from

few randomized treatment studies that potentially isolated training effects, all reviewed papers established correlational designs or studied pre-existing groups and thus cannot provide direct evidence for the relative contributions of nature or nurture conditions. Nevertheless, it is worthwhile to consider implications of certain findings for this debate.

Without exception, all the studies on people with amusia suggested that vocal emotion perception deficits can be associated with a congenital music perception impairment. In that sense, the link between musicality and vocal emotion perception seems to occur in the absence of training effects and might therefore be mediated by genetic factors. These may have evolved in parallel with acoustic similarities between vocal and musical emotions (Juslin & Laukka, 2003) and may be expressed in overlapping neural circuits involved in recognizing basic emotions from voices and music (see also Fröhholz et al., 2016). As a qualification, Bigand and Poulin-Charronnat (2006) showed that a remarkable degree of auditory sophistication can be acquired through exposure to music only, without explicit training. Accordingly, it remains possible that these implicit musical learning processes could be limited in people with amusia if they avoid exposure to music because they enjoy it less. Thus, while the limited vocal emotion capacities observed in amusia could hint towards a genetic predisposition, they could also result in part from selective exposure.

At the same time, a consistent set of findings from highly trained musicians suggests that explicit musical training does play a central role for the development of auditory and vocal perceptual skills. This points towards an influence of environmental factors, but there is always a possible confound with natural inclination, as people with better auditory skills may be more likely to start and pursue musical training (Pantev & Herholz, 2011). Accordingly, Dmitrieva et al. (2006) observed superior vocal emotion capacities in a very young group of musicians, who presumably had very little musical training yet but might have been selected for musical education based on their auditory sensitivity. Note that many authors who found the musician effect on vocal emotion perception argued that it is very unlikely that it is entirely based on predispositional differences (Lima & Castro, 2011; Strait et al., 2009; Thompson et al., 2004): On the one hand, the effect was still present when participants

were matched in socio-educational variables, general intelligence, cognitive control, and personality traits (Lima & Castro, 2011). On the other hand, some studies found a correlation between emotion perception capacities and years of musical education, suggesting a clear impact of training duration (Parsons et al., 2014; Twaite, 2016; K. S. Young et al., 2012). However, this could also reflect a gene-environment interaction since people who have a dispositional aptitude might stick longer with the training. Further, vocal emotion perception was found to be related to age at training onset (Strait et al., 2009). Although it is often difficult to disentangle age at onset with years of musical training, this could suggest a sensitive period for the acquisition of some music-training induced skills. Accordingly, many studies required musicians to have started training before the age of seven (refer to Table 1).

Finally, a few intervention studies with randomized assignment to treatment and control groups aimed at isolating learning effects of musical training and succeeded to improve vocal emotion perception in the healthy population. Note that these interventions were qualitatively different to more “natural” settings of musical education, where the focus lies on mastery of an instrument or the singing voice. They were shorter and often particularly focused on emotion expression in music (Bodner et al., 2012; Mualem & Lavidor, 2015), apart from Thompson et al. (2004), who randomly assigned children to one year of keyboard and singing lessons, but found mixed results. Likewise, studies on cochlea implant users showed that musical training can improve vocal emotion perception in this particular group; but again, those interventions had an entirely different purpose than in normal hearing participants: instead of fine-tuning a healthy auditory system, CI users have to learn how to restore perception from a severely degraded input. Music-based interventions may be particularly effective in groups with poor auditory resolution to improve sensitivity to auditory cues in the vocal domain (Fuller et al., 2018; Good et al., 2017). Overall, while it may be difficult to generalize the results of these intervention studies to settings of instrumental or vocal music lessons, they show that vocal emotion perception is amenable to musical training in some circumstances. Accordingly, it seems worthwhile to incorporate emotionally oriented teaching units in music lessons or treatment programs.

Active Engagement in Musical Activities vs Receptive Training

Several studies suggest that active engagement in a musical task is a crucial factor. They compared purely receptive training to auditory-motor training and reported stable benefits in the vocal emotion domain for auditory-motor training (Chari et al., 2020; Fuller et al., 2018). There is high consensus in the neuroscientific literature, that active engagement in music and the synchronized tuning of auditory, visual, somatosensory, and motor processes is a driving force to adaptive neuroplasticity (Kraus & Chandrasekaran, 2010; Kraus & White-Schwoch, 2017; Palomar-García et al., 2017). Specifically, it has been shown that sensorimotor musical training leads to more robust changes in the auditory cortex compared to pure receptive training (Lappe et al., 2008). This surely does not imply that purely receptive music training is ineffective (Bigand & Poulin-Charronnat, 2006) – but motor engagement may add a boost to the auditory fine-tuning process during training. This could be of particular relevance for cochlear implant users (Lehmann & Paquette, 2015), who during rehabilitation face the challenge of massive post-implantation adaptation to the new auditory input. Here, auditory-motor interventions could be particularly efficient to foster neuroplasticity in auditory areas and aid hearing rehabilitation.

The Role of Different Acoustic Cues and Supramodal Processes

Previous literature suggests that musicians show superior processing of pitch, temporal and timbral cues (Elmer et al., 2018). The present review reveals that superior pitch processing capacities in people with high levels of musicality are particularly tightly associated with vocal emotion perception. On the one hand, pitch discrimination performance was correlated with emotion perception performance in musicians; on the other hand, there was strong agreement that impaired pitch processing was a key deficit in people with amusia accounting for impairments in the domain of vocal emotions. However, this conclusion has its limitations, since amusia was often *defined* only based on low scores in the pitch subsets of the MBEA (refer to Table 1). According to Juslin and

Laukka (2003), pitch and timbral cues are highly relevant for vocal emotion perception, but timing parameters like speech rate were found to be equally important. The potential role of timing was largely neglected in all reviewed studies, despite its central role in music, therein often referred to as tempo and rhythm. Lagrois and Peretz (2019) showed that pitch and rhythm deficits are often linked in people with amusia, but they sometimes can appear as distinct disorders. In parallel, there is current evidence for different brain mechanisms to process harmonic versus rhythmic structures in music (Sun et al., 2020). In the future, it would be very informative to investigate vocal emotion perception in people with specific impairments in the temporal domain of music.

Alongside the notion that enhanced sensitivity to acoustic cues may lead to better emotion perception in people with higher level of musicality, it was also suggested that there might be a domain-general supramodal process that mediates the link between musicality and emotional perception across domains (Schellenberg & Mankarious, 2012; Trimmer & Cuddy, 2008). Lima and Castro (2011) suggested that musical training might increase the level of “emotional granularity”, meaning a more fine-grained conceptualization and differentiation of emotions, that in turn could aid emotional perception in other domains. However, although the involvement of supramodal processes seems plausible, the reviewed brain data suggest that modulatory effects of musicality can be observed in very early processing steps of vocal emotions, which are associated with a basic analysis of auditory cues and detection of emotional saliency (Schirmer & Kotz, 2006). Hence, the link between musicality and vocal emotion perception seems to be based, at least partially, on a more sophisticated analysis of auditory cues.

Identification of Relevant Topics for Future Research

The findings surveyed in this paper highlight many relevant aspects that can guide future research regarding relationships between musicality and vocal emotion perception. We hope this article will inform systematic research programs with better powered designs and standardized research

materials, and ultimately promote a refined understanding of the putative common mechanisms underlying musicality and vocal emotion perception. Unfortunately, neuroscientific research in this field is still sparse and unsystematic, and the heterogeneity of the above studies illustrates the need for more systematic research on candidate subcortical and cortical mechanisms to mediate the link between musicality and vocal emotion perception. Important questions for neuroscientific research include how perceptual neuroplasticity is induced in musicians, how this relates to motor plasticity in musicians' brains (Elbert et al., 1995), what are the relative roles of training or ongoing maintenance (Merrett et al., 2013), and how each of these aspects relates to vocal emotion perception. Moreover, a particularly relevant comparison in the context of vocal emotion perception is the one between singers and instrumentalists. Most of the reviewed studies only included instrumentalists or did not report on that matter. Only Thompson et al. (2004) compared participants with piano and singing lessons, and their results suggested that the singing lessons might even hinder vocal emotion perception, perhaps because the vocal patterns that are trained during singing lessons may conflict with natural vocal emotion expression. Another neglected but related field is the link between musicality and emotion production. It may be reasonable to assume that people who are highly trained in an emotionally expressive art have an advantage in vocal expression of emotion.

Conclusion and Outlook

In this review, we systematically identified and discussed the current state of research regarding a link between musicality and vocal emotion perception. Overall, the available evidence suggests that musicality is indeed associated with better vocal emotion perception performance. Since adequate perception of vocal emotions forms a fundamental prerequisite for everyday social interaction, these results also may add weight to the presumed importance of music and musical education for personal development and quality of life. Musical training can provide a promising supplemental intervention for people who struggle with vocal emotion perception, and while supporting evidence can now be considered strong in the case of cochlear implant users, future applied research seems

promising in the context of other target groups as well (e.g., individuals with autism, or with high-level auditory impairments). Although data often do not allow for causal inferences, their combined consideration can provide useful information for the question of how different factors of nature and nurture contribute to related skills of emotion perception in the domains of voice and music.

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Conflicts of Interests

The authors declare no conflicts of interests.

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Table 1: Summary of empirical articles on musicality and vocal emotion perception that met the selection criteria

Reference	Sample (Mean Age)	Inclusion Criteria	Stimuli and Task	Emotions	Results
Musical Expertise		<i>Musicians</i>			
Başkent et al., 2018	10 musicians (12 y), 11 non-musicians (12 y)	training onset before age 7 yrs, > 5 yrs of musical training, regular training within the last 3 yrs	original and degraded speech, melodic contour identification, vocal emotion identification, and speech understanding in noise	joy, anger, sadness, and relief	musician effect only in melodic contour identification in degraded speech condition
Dmitrieva et al., 2006	48 musicians, 46 controls (3 age groups: 7–10 y , 11–13 y , and 14–17 y)	recruited from the Russian National Orchestra, St. Petersburg	vocal emotion identification, presentation to one ear with white noise on the other	joy, anger, and neutral	Musicians were better and faster in emotion recognition
Fuller et al., 2014	25 musicians (23 y), 25 non-musicians (22 y)	training onset before age 7 yrs, > 10 yrs of musical training, regular training within the last 3 yrs	original and degraded (8-channel simulated) stimuli, tests on speech, vocal emotion, and melodic contour identification	joy, anger,sadness, and relief	musicians better in emotion recognition in both original and degraded condition
Lima & Castro, 2011	40 musicians, 40 non-musicians (2 age groups: 18-30 y and 40-60 y)	instrumentalists, > 8 years of musical training, started in childhood, current regular practise	vocal emotion identification and intensity rating	happines, anger, fear, sadness, surprise, disgust, and neutral	musicians were better in emotion recognition, controlled for cognitive differences

Note: VER = vocal emotion recognition, MBEA = Montreal Battery of Evaluation of Amusia (Peretz et al., 2003)

Table 1: Summary of empirical articles on musicality and vocal emotion perception that met the selection criteria **continued**

Reference	Sample (Mean Age)	Inclusion Criteria	Stimuli and Task	Emotions	Results
Nilssonne & Sundberg, 1985	62 musicians (21 y) / 51 controls (law students, 24 y)	music conservatory students	fundamental frequency contours extracted from utterances, presentation in pairs, choice which was during depression	depression vs recovery	musicians made fewer errors
Parsons et al., 2014	109 (29 y): parents /non-parents (25/26 musicians; 29/29 non-musicians, respectively)	> 4 years of formal music training	pairs of infant cries, only differing in pitch, participants decided which of the two infants sounded more distressed	distressed infant cries	advantage for parents with musical training, increasing with years of musical training, no musical training effect in non-parents
Twaite, 2016	58 (22 y) musicians /61 non-musicians (21 y)	instrumentalists, > 8 years of musical training, training onset before 12, currently > 2 hrs weekly practise	emotion perception in prosodic, lexical, facial and musical channel	happiness, anger, fear, sadness, surprise, disgust, and interest	musicians better in the emotion recognition in the prosodic and the musical channel
Weijkamp & Sadakata, 2017	16 musicians (29 y) / 16 non-musicians (22)	instrumentalists, > 5 years of musical training, currently > 2.5 hrs weekly practise	audiovisual Stroop Task, judging the emotion of either the face or the voice, plus unimodal classification tasks	happiness, sadness, neutral	no group differences in unimodal tasks, but musicians better in the audiovisual tasks (for both faces and voices)

Note: VER = vocal emotion recognition, MBEA = Montreal Battery of Evaluation of Amusia (Peretz et al., 2003)

Table 1: Summary of empirical articles on musicality and vocal emotion perception that met the selection criteria **continued**

Reference	Sample (Mean Age)	Inclusion Criteria	Stimuli and Task	Emotions	Results
Young et al., 2012	57 (27 y): depressed/ healthy (13 /15 musicians, 14 /15 non- musicians, respectively)	> 4 years of formal music training	pairs of infant cries, only differing in pitch, participants decided which of the two infants sounded more distressed	distressed infant cries	effect of musical training, even during depression, correlation between task score and years of musical training
Thompson et al., 2004	Exp1: 9 musicians, 11 non-musicians (adults); Exp2: 28 musicians, 28 non-musicians (adults); Exp3: 43, all 7-year-old	> 8 years of formal music training, training onset during childhood	Exp1, Exp2 : VER in spoken sentences or melodic analogues; Exp3: VER after 1-year of keyboard, singing, drama, or nothing	happiness, anger, fear, sadness, and neutral	Exp1, Exp2 : musicians performed better than non-musicians; Exp3: keyboard and drama better than nothing, no effect of singing
Neuroimaging					
Nolden et al., 2017	17 musicians (25y) / 20 non-musicians (25 y)	> 5 years of musical training, daily instrument practice	music and vocal stimuli, task: pure tones detection, EEG recording, oscillatory analysis (theta, alpha, beta, gamma bands)	happiness, fear, sadness, and neutral	effects of expertise in the alpha and theta bands (greater activation in musicians in both frequency bands)
Park et al., 2015	12 musicians (20 y) / 12 non-musicians (19 y)	instrumentalists, received formal music training	fMRI scans with passive listening followed by a session with emotion classification	happiness, fear, sadness, and neutral	increased activation in musicians frontal gyrus, posterior cingulate cortex and the retrosplenial cortex, for sad stimuli only

Note: VER = vocal emotion recognition, MBEA = Montreal Battery of Evaluation of Amusia (Peretz et al., 2003)

Table 1: Summary of empirical articles on musicality and vocal emotion perception that met the selection criteria **continued**

Reference	Sample (Mean Age)	Inclusion Criteria	Stimuli and Task	Emotions	Results
		(mean years of training = 13.8, SD = 2.6)			
Pinheiro et al., 2015	14 musicians (23 y) / 14 non-musicians (23 y)	> 8 years musical training, daily instrument practice	emotion classification with intelligible semantic content (SCC) or unintelligible semantic content (PPC), EEG recording	happiness, anger and neutral	P50 more positive in controls than musician in SCC only, musicians better in recognition of anger in PCC only
Rigoulot et al., 2015	15 musicians (24 y) / 18 non-musicians (25 y)	> 5 years of musical training, daily instrument practice	music and vocal stimuli, task: pure tones detection, EEG recording	happiness, fear, sadness, and neutral	differential electrophysiological response to vocal and music stimuli for musicians and non-musicians
Strait et al., 2009	30 adults (25 y), musicians (by onset age: n = 11; by years: n = 15)/ non-musicians (n = 19/15, respectively)	'musicians by onset age': training onset before age 7, 'musicians by years': > 10 years musical training	exposure to infants unhappy cries, recording of auditory brainstem responses, during a complex and more periodic part of the stimulus	infant cries	in musicians, subcortical activation is enhanced during complex portion of the sound and decreased during more periodic portion
Musical training /intervention					
Bodner et al., 2012	80 (29 y): 39 with social anxiety disorder, 41 healthy controls	-	Intervention: training of happiness recognition in music, Test: VER, pre/post-design	happiness, anger, fear, sadness, and surprise	music intervention improved recognition of vocal happiness in participants with social anxiety

Note: VER = vocal emotion recognition, MBEA = Montreal Battery of Evaluation of Amusia (Peretz et al., 2003)

Table 1: Summary of empirical articles on musicality and vocal emotion perception that met the selection criteria **continued**

Reference	Sample (Mean Age)	Inclusion Criteria	Stimuli and Task	Emotions	Results
Mualem et al., 2015	Exp 1: 12 intervention group (24 y) 12 control group (25 y); Exp 2: 23 musicians (26 y)	> 6 years of formal music training	Intervention: 4 x 30 min music sessions, control: art session, focused on emotion expression; Test: VER, pre/post-design	happiness, anger, fear, sadness, and neutral	Exp1: intervention group better than control group in VER, Exp2: no difference between musicians and non-musicians
Nashkoff 2007	42 intervention group, 39 controls	-	Intervention: Pitch discrimination practice (8 weeks), Test: VER, pre/post-design	happiness, fear, sadness, and ambiguous	VER improved after intervention
Cochlear implants					
Chari et al., 2020	18 CI users (62 y), postlingually deafened	-	Intervention: auditory-motor, auditory-only, or no training (3 months); Test: speech, music and VER tests, pre/post-design	happiness, anger, fear, sadness and neutral	training effects only in melodic contour identification task
Fuller et al., 2018	19 CI users (69 y), postlingually deafened	-	Intervention: music-therapy, pitch/timbre group, or control (6 weeks); Test: speech, music and VER tests, pre/post-design	joy, anger, sadness, and relief	Improvement of VER in music-therapy group, improvement of melodic contour identification in pitch/timbre group

Note: VER = vocal emotion recognition, MBEA = Montreal Battery of Evaluation of Amusia (Peretz et al., 2003)

Table 1: Summary of empirical articles on musicality and vocal emotion perception that met the selection criteria **continued**

Reference	Sample (Mean Age)	Inclusion Criteria	Stimuli and Task	Emotions	Results
Good et al., 2017	18 CI users, children (10 y)	-	Intervention: music (piano) or art training (painting), 6 months; Test: music and VER tests; pre-, mid-, post-design	happiness, anger, fear, and sadness	music perception and emotional speech prosody perception improved in the music group compared to the art group
Petersen et al., 2012	18 CI users (53 y), 6 NH controls (54 y)	-	Intervention: 6 month one-to-one musical ear-training, or control (no task); Test: speech, music and VER tests; pre-, mid-, post-design	happiness and sadness	in music group; earlier onset in improvement of emotional prosody perception; both CI groups still worse than NH controls
Waaramaa et al., 2018	25 CI users (12 y) and 18 NH controls (12 y)	-	vocal emotion identification task, self-reported musical interests and measurements of acoustic parameters of the stimuli	anger, fear, excitement, and contentment	NH controls performed better than CI users, musical interests and voice quality parameters related to correct identification in both groups
Congenital Amusia		<i>Amusia</i>			
Cheung et al., 2020	20 participants with amusia (22 y), 17 controls (22 y), all Cantonese speakers	global MBEA score < 71 %	emotion prosody rating task, emotion judgment task of written words, valence judgment task of written words	happiness, anger, fear, and sadness	participants with amusia performed worse in VER task than controls, no difference in tasks with written words

Note: VER = vocal emotion recognition, MBEA = Montreal Battery of Evaluation of Amusia (Peretz et al., 2003)

Table 1: Summary of empirical articles on musicality and vocal emotion perception that met the selection criteria **continued**

Reference	Sample (Mean Age)	Inclusion Criteria	Stimuli and Task	Emotions	Results
Lima et al., 2016	13 participants with amusia (58 y), 11 controls (53 y)	pitch-based MBEA scores more than 2 SD below population average (~72%)	Exp 1: rating of emotions in voices and faces, Exp 2: ratings of spontaneous and posed laughs	anger, fear, sadness, disgust, relief, amusement, and pleasure; laughs	Exp 1: impairments in amusia for all stimulus types; Exp 2: participants with amusia show decreased sensitivity to authenticity of laughs
Lolli et al., 2015	Exp 1: 40 (aged 18-22), 9 considered amusic; Exp 2: 29 (aged 18-28), 3 considered amusic	pitch threshold > 16 Hz in pitch discrimination task	Exp1: VER, low-pass filtered (500Hz) and unfiltered speech; Exp 2: high-pass filtered (4800Hz) and unfiltered speech	happiness, fear, sadness, irritation, tenderness and neutral	Exp 1: impairments in amusia in the low-pass filtered but not in the unfiltered condition; Exp 2: no differences
Pralus et al., 2019	18 participants with amusia (33 y), 18 controls (35 y)	global MBEA score < 23/30 (76 %) and/or a MBEA pitch score < 22/30 (73%)	emotion categorization and intensity rating of emotional sentences and vowels	joy, anger, fear, sadness, and neutral	worse performance of participants with amusia on vowels but not sentences; intensity ratings: no differences
Thompson et al., 2012	12 participants with amusia (50 y), 12 controls (46 y)	MBEA scale subtest score < 22/30 (73%) on two consecutive occasions	VER; self-report questionnaire on emotional prosody perception in daily life	happiness, fear, sadness, tenderness, irritation, and neutral	VER: participants with amusia worse than controls; report awareness of VER problems in daily life

Note: VER = vocal emotion recognition, MBEA = Montreal Battery of Evaluation of Amusia (Peretz et al., 2003)

Table 1: Summary of empirical articles on musicality and vocal emotion perception that met the selection criteria **continued**

Reference	Sample (Mean Age)	Inclusion Criteria	Stimuli and Task	Emotions	Results
Zhang et al., 2018	19 participants with amusia (23 y), 19 controls (23 y), all Mandarin speakers	pitch-based MBEA score < 65/90 (72%)	Vocal emotion recognition, speech and non-speech (low-pass filtered at 500 Hz) condition	happiness, anger, fear, sadness, surprise, and neutral	performance of participants with amusia worse than controls, for all emotions and conditions
Individual differences					
Dibben et al., 2018	52 (32 y)	-	ratings of perceived emotion in music and speech; questionnaires on personality, emotional intelligence and musical training	valence and arousal	ratings associated with emotional stability, agreeableness, musical training (but for musical stimuli only) and age
Globerson et al., 2013	Exp 1: 60 (25 y); Exp 2: 37 (25 y)	-	Exp 1, Exp2: prosody recognition tasks (pragmatic and emotional) and different psychoacoustic tasks	happiness, anger, fear, and sadness	psychoacoustic thresholds explained 31% and 38% of affective and pragmatic prosody recognition performance
Trimmer & Cuddy, 2008	100 (22 y)	-	VER of speech utterances and melodic analogues; tests on intelligence, emotional intelligence and musical abilities	joy, anger, fear, sadness and neutral	emotional intelligence, not musical training predicted vocal emotion recognition performance

Note: VER = vocal emotion recognition, MBEA = Montreal Battery of Evaluation of Amusia (Peretz et al., 2003)

Table 1: Summary of empirical articles on musicality and vocal emotion perception that met the selection criteria **continued**

Reference	Sample (Mean Age)	Inclusion Criteria	Stimuli and Task	Emotions	Results
Waaramaa & Leisiö, 2013	250; 50 per country	-	vocal emotion recognition task	happiness, anger,	emotion recognition performance above chance
	(Finland 48 y, Russia 35		with replay-option; questionnaire	fear, sadness,	in all countries, musical interests tended to have a
	y, Estonia 32 y, Sweden		on musical interests	surprise, disgust,	positive effect on VER
	27 y, and the USA 23 y)			interest and neutral	

Note: VER = vocal emotion recognition, MBEA = Montreal Battery of Evaluation of Amusia (Peretz et al., 2003)