visual recognition of objects and scenes. Thus, learning about faces involves several different learning tasks made even harder by the fact that they operate with the same input and are thus subject to interference effects.

Conclusions

Recent studies provide an important piece of the jigsaw in our understanding of the development and neural basis of face processing. The developmental perspective on the debate from adult studies (about the specificity or otherwise of face processing areas in cortex) offers an intriguing middle-ground view. That is, the FFA and related areas, such as the superior temporal sulcus, might begin with connection and architectural biases sufficient to ensure that they are activated by the presence of faces in the visual field of the infant. However, it is only after years of exposure to faces that the neural architecture of these regions becomes specifically tuned for processing this particular class of visual stimulus to the relative exclusion of other stimuli. This process might also depend on the developmental timing of synaptic and dentritic pruning. Thus, although the end result of development is a region largely specialized for face processing, this specificity is achieved through a complex combination of experience and subtle initial biases. Future research could focus on further tracing the developmental time-course of face processing in the human brain through the use of a new optical imaging method readily applicable to infants (near infrared spectroscopy [15]), and on the differential specialization of different regions of the cortical social brain network. Moreover, it will be worthwhile to explore whether the emerging developmental story for faces also holds for other domains of stimulus processing, such as speech perception. In this respect, data from infants as young as three months indicate that speech sounds can activate some similar speech and language processing areas as are observed in adults [16]. However, how speech-selective these speech-sensitive areas of cortex are remains to be determined, and it is possible that in infants and children some complex natural sounds could activate the same regions as strongly as speech itself.

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The linguistic benefits of musical abilities

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Growing evidence points to a link between musical abilities and certain phonetic and prosodic skills in language. However, the mechanisms that underlie these relations are not well understood. A recent study by Wong *et al.* suggests that musical training sharpens the subcortical encoding of linguistic pitch patterns. We consider the implications of their methods and findings for establishing a link between musical training and phonetic abilities more generally.

Musical and linguistic abilities: what is the relationship?

Music and language rely on richly structured sound sequences. Is there any relationship between processing abilities in the two domains? Several studies have reported associations between musical ability and accuracy at perceiving phonetic or prosodic contrasts in a native or foreign

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language (e.g. [1–5]). However, the brain mechanisms mediating these benefits have not been well understood. A recent study by Wong *et al.* [6] suggests that musical experience tunes basic auditory sensory processing circuitry in the brain, which has consequences for language processing.

Musical abilities and pitch-related linguistic abilities

The study of Wong *et al.* study focused on the processing of pitch. Pitch is a highly structured aspect of music and is also used to convey linguistic information. All languages use pitch to convey prosody and approximately half the world's languages use pitch to make lexical distinctions between words. In such 'tone languages', the same word spoken with a different pitch pattern has an entirely different meaning. For example, in Mandarin Chinese, the syllable /mi/ (pronounced 'me') means 'to squint' or 'bewilder' when spoken with a level versus rising pitch, respectively.

Wong *et al.* used the scalp-recorded electroencephalogram (EEG) to examine subcortical processing of lexical tones. They focused on an oscillatory neural response to sound known as the frequency following response (FFR), which is thought to be generated in the inferior colliculus of the brainstem and possibly also in lower structures [7,8] (Figure 1). The FFR has an interesting relationship with voice pitch in that its oscillation contains considerable energy at the fundamental frequency (F0) of the voice and can track linguistically relevant F0 changes dynamically over short time scales (such as a single syllable, ~250 ms in duration). Previous research had examined the FFR during perception of lexical tones. Specifically, Krishnan *et al.* examined the FFR during perception of Mandarin monosyllables and

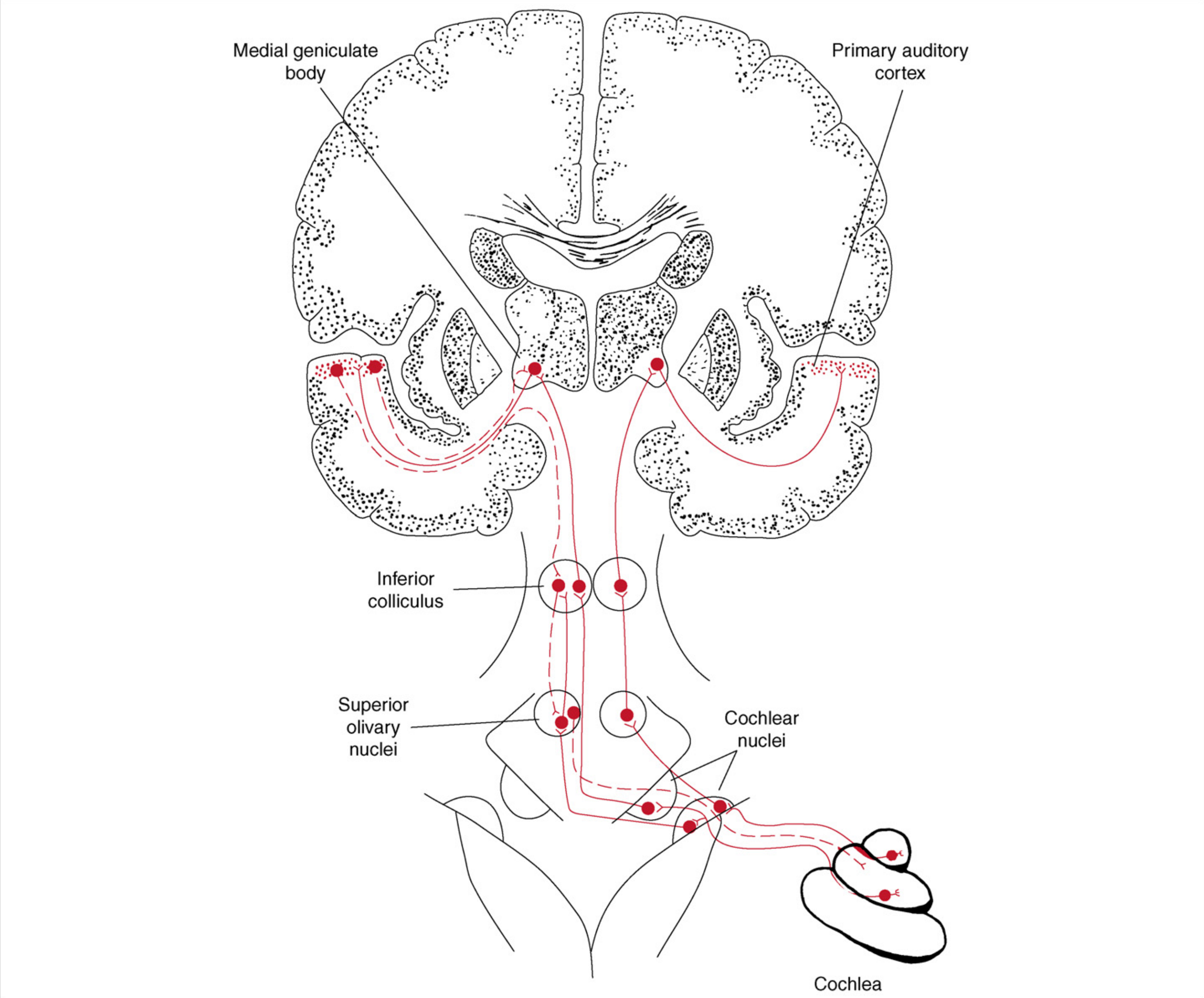

Figure 1. Bottom-up and top-down neural connections in the auditory system. Note the subcortical location of the inferior colliculus, which is the presumptive origin of the frequency-following response (FFR) studied by Wong *et al.* [6]. Unbroken red lines show ascending auditory pathways, leading from the cochlea through the brain stem (cochlear nucleus, superior olivary complex, inferior colliculus) and the thalamus (medial geniculate body) to the auditory cortex. Broken red lines indicate descending ('corticofugal') pathways connecting high levels to lower ones. Wong *et al.* propose that such projections are responsible for top-down tuning of subcortical sound processing. Adapted from [8], with permission.

found that the quality of F0 tracking was superior in native Mandarin speakers than in native English speakers [9]. This suggested that linguistic auditory experience could tune subcortical sound processing mechanisms.

Wong *et al.* extended this work by examining F0 tracking of Mandarin monosyllables in musicians versus non-musicians, neither of whom had prior familiarity with Mandarin. Participants heard the syllable /mi/ spoken with three different lexical tones in the background as they watched a movie. Wong *et al.* found that that the quality of F0 tracking was superior in musicians. They also found positive correlations between F0 tracking quality and the amount of musical training and between F0 tracking quality and performance on identification and discrimination of Mandarin syllables.

These findings are surprising because they suggest that musical experience influences speech processing at a subcortical level. Wong *et al.* propose that their findings reflect long-term tuning of brainstem sensory circuitry by descending neural projections from the auditory cortex onto subcortical centers. Such top-down neural connections are known to exist (Figure 1) and presumably mediate the improved FFR F0 tracking seen by Krishnan *et al.* [9]. The cross-domain approach used by Wong *et al.* to pitch processing thus provides new avenues for exploring the functional role of these little-studied ‘corticofugal’ pathways.

One question about the study of Wong *et al.* concerns its relevance to linguistic (versus acoustic) processing because their participants were never asked to use pitch for language learning. This concern has been addressed by a different study in which native English speakers (with no prior knowledge of tone languages) learned a vocabulary of six nonsense syllables, each of which was paired with three lexical tones [5]. (For example, the syllable ‘pesh’ meant glass, pencil or table depending on whether it was spoken with a level, rising, or falling tone). Participants underwent a training program in which each syllable (plus lexical tone) was heard while viewing a picture of the word’s meaning and in which quizzes were given periodically to measure word learning. Each participant continued training until their word identification ability reached a plateau. Two groups emerged: ‘successful learners’ and ‘less-successful learners’, defined by their final level of performance. For the current purposes, one relevant finding was that successful versus less-successful learners differed in their amount of prior musical training, suggesting that musical ability is relevant for real language skills.

Although the studies of Wong and colleagues have focused on lexical tones, their findings are probably relevant to studies that have found links between musical training and pitch-related prosodic abilities. For example, musically trained French-speaking adults and children show increased sensitivity to subtle pitch variations in intonation contours, which is reflected in both behavioral measures and cortical evoked potentials [3,10]. Furthermore, musically trained English-speaking adults and children show advantages in identifying the emotional tone of sentences based on prosodic cues, both in their own language and in an unfamiliar foreign language [2]. Before the study of Wong *et al.*, these findings seemed best accounted for by the influence of musical experience on auditory cortical circuitry (cf. [11]). However, this study raises the alternative possibility that musical experience benefits prosodic perception by more accurate encoding of pitch patterns in subcortical centers; it also draws attention to the need to study the effects of musical training at multiple neural levels.

Musical abilities and non-pitch-related linguistic abilities

Although Wong *et al.* have focused on lexical pitch processing, the study of auditory brainstem responses could be profitably extended to study more general links between musical ability and phonemic skills. There is now behavioral evidence that musical ability relates to non-pitch-related phonemic abilities, such as children’s reading ability in a first language or adult discrimination and production of subtle phonemic contrasts in a second language [1,4]. Notably, these findings have emerged in studies that have controlled carefully for various confounding variables, such as auditory memory. Because music relies on fine distinctions in pitch, timbre and duration, it might be that musical training enhances basic spectrotemporal sound-encoding mechanisms that are also relevant for speech [12]. This hypothesis could be tested by measuring brainstem encoding of non-pitch-based phonemic contrasts before and after musical training.

The need for experimental studies

Most data showing an association between musical and linguistic skills (including [6]) are correlational. A possible confound in such studies is that individuals who do versus do not seek out extensive musical training might have preexisting neural differences relevant for speech processing (cf. [13]). Therefore, to accurately assess the role of musical experience in shaping linguistic abilities, longitudinal studies are needed in which groups are matched at the outset on various neural and behavioral measures of auditory processing and are tested for linguistic skills before and after musical (versus alternative) training (cf. [14]). If musical training improves linguistic abilities, a variety of neural techniques could then be brought to bear to study the nature of the mechanisms mediating this relationship.

Conclusion

Studies examining the influence of musical training on language abilities are relevant to theoretical debates over the modularity of language processing and also for practical issues, such as the importance of music in education and rehabilitation. There do appear to be links between musical abilities and certain phonetic and prosodic abilities, however, the bases of these links has not been clear. A study by Wong *et al.* provides evidence that musical training sharpens the sensory encoding of pitch patterns at a surprisingly early stage of brain processing [6]. The study enriches a growing body of empirical research investigating cognitive and neural relations between music and language [15].

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Erratum

Erratum: Teachers in the wild: some clarification

[*Trends in Cognitive Sciences* 11 (2007), 272–273]

In the article 'Teachers in the wild: some clarification' in the July issue of *Trends in Cognitive Sciences* (Vol. 11, No. 7, pp. 272–273) the corresponding author details were incorrectly reported. The author for correspondence is Alex Thornton: jant2@cam.ac.uk.

We apologize for this oversight to the author and readers of *Trends in Cognitive Sciences*.

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Corrigendum: The proactive brain: using analogies and associations to generate predictions

[*Trends in Cognitive Sciences* 11 (2007), 280–289]

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The author regrets that there was a mistake in reference [37] in the above article. The correct reference is:

Oliva, A. and Torralba, A. (2001) Modeling the shape of the scene: a holistic representation of the spatial envelope. *Int. J. Comput. Vis.* 42, 145–175.

The author sincerely apologizes for any problems that this error may have caused.

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