**Music and multimodal mental imagery**

**Bence Nanay**

**I. Introduction**

Mental imagery is early perceptual processing that is not triggered by corresponding sensory stimulation in the relevant sense modality. Multimodal mental imagery is early perceptual processing that is triggered by sensory stimulation in a different sense modality. For example, when early visual or tactile processing is triggered by auditory sensory stimulation, this amounts to multimodal mental imagery. Pulling together philosophy, psychology and neuroscience, I will argue in this paper that multimodal mental imagery plays a crucial role in our engagement with musical works. Engagement with musical works is normally a multimodal phenomenon, where we get input from a number of sense modalities. But even if we screen out any input that is not auditory, multimodal mental imagery will still play an important role that musicians and composers often actively rely on.

The plan of the paper is the following. In Section II, I outline a fairly wide conception of mental imagery, which is very close to how psychologists and neuroscientists use this concept and zero in on an important, but thus far relatively unexplored form of mental imagery, which I call multimodal mental imagery. In Section III, I highlight the importance of auditory mental imagery in listening to music. In Section IV, I argue that multimodal mental imagery also plays a crucial role in listening to music. Finally, in Section V, I show why we should all care about this.

**II. Multimodal mental imagery**

Mental imagery, as psychologists and neuroscientists understand the concept, is early perceptual processing not triggered by corresponding sensory stimulation in the relevant sense modality (Kosslyn et al. 2006, Pearson et al. 2015, Nanay 2015, 2018). For example, visual imagery is early visual processing (say, in the primary visual cortex) not triggered by corresponding sensory stimulation in the visual sense modality (that is, not triggered by corresponding retinal input).

Mental imagery is defined negatively: it is early perceptual processing *not* triggered by corresponding sensory stimulation in the relevant sense modality. But then what is it triggered by? It can be triggered, in a purely top-down manner, say, when you close your eyes and visualize an apple. But it can also be triggered laterally by other sense modalities. This is multimodal mental imagery. Multimodal mental imagery is early perceptual processing in one sense modality triggered by sensory stimulation in a different sense modality.

When you have early auditory processing that is triggered by sensory stimulation in the visual sense modality, this counts as multimodal mental imagery. This is what happens, when, for example, you watch the tv muted (e.g., Calvert et al., 1997; Hertrich, Dietrich, & Ackermann, 2011; Pekkola et al., 2005). Conversely, if you have early visual processing that is triggered by sensory stimulation in another sense modality, this also counts as multimodal mental imagery.

Another example of multimodal mental imagery (which I will come back to) is the double flash illusion. You are presented with one flash and two beeps simultaneously (Shams et al. 2000). So the sensory stimulation in the visual sense modality is one flash. But you experience two flashes and already in the primary visual cortex, two flashes are processed (Watkins et al. 2006). This means that the double flash illusion is really about multimodal mental imagery: we have perceptual processing in the visual sense modality (again, already in V1) that is not triggered by corresponding sensory stimulation in the visual sense modality (but by sensory stimulation in the auditory sense modality).

I need to make some clarificatory remarks about the concept of multimodal mental imagery. First, not everybody will agree with my use of the term ‘mental imagery’ (which I borrow from the standard usage in psychology and neuroscience). Nothing depends on the label ‘mental imagery’ in the argument that follows. Those who have very strong views about how this concept should or should not be used should read the rest of the argument to be about mental imagery\* (which is defined as early perceptual processing not triggered by corresponding sensory stimulation in the relevant sense modality).

Second, mental imagery may or may not be voluntary. When you close your eyes and visualize an apple, this is an instance of voluntary mental imagery. But not all mental imagery is voluntary. Unwanted flashbacks to an unpleasant scene or earworms in the auditory sense modality would be examples for involuntary mental imagery.

Third, mental imagery may or may not localize its object in one’s egocentric space. When we visualize an apple, we often do so in such a way that the apple is represented in some kind of abstract visualized space, so that it would make little sense to ask whether you could reach the apple or how far the apple is from the tip of your nose. But this is, again, not a necessary feature of mental imagery. We can also visualize an apple on the pages of this book you are reading.

Finally, and most controversially, perceptual processing may be conscious or unconscious. We know from many many experimental studies that perception, that is, sensory stimulation-driven perceptual processing, can be unconscious (Weiskrantz 1997, 2009, Kentridge et al. 1999, Kouider & Dehaene 2007, Goodale & Milner 2004). So there is no prima facie reason why mental imagery, that is, non-sensory stimulation-driven perceptual processing, would have to be conscious. Just as perceptual processing in general, perceptual processing that is not triggered by corresponding sensory stimulation in the relevant sense modality may also be conscious or unconscious (see Nanay 2018, forthcoming).

**III. Music and auditory mental imagery**

Expectations play a crucial role in our engagement with music (and art in general). When we are listening to a song, even when we hear it for the first time, we have some expectations of how it will continue. And when it is a tune we are familiar with, this expectation can be quite strong (and easy to study experimentally). When we hear Ta-Ta-Ta at the beginning of the first movement of Beethoven’s *Fifth Symphony* in C minor, Op. 67 (1808), we will strongly anticipate the closing Taaam of the Ta-Ta-Ta-Taaaam.

Much of our expectations are fairly indeterminate: when we are listening to a musical piece we have never heard before, we will still have some expectations of how a tune will continue, but we don’t know what exactly will happen. We can rule out that the violin glissando will continue with the sounds of a beeping alarm clock (unless it’s a really avant-garde piece…), but we can’t predict with great certainty how exactly it will continue. Our expectations are malleable and dynamic: they change as we listen to the piece.

Expectations are mental states that are about how the musical piece will unfold. So they are future-directed mental states. But this leaves open just what kind of mental states they are – how they are structured, how they represent this upcoming future event and so on. I will argue that at least some forms of expectations in fact count as mental imagery. And musical expectations (of the kind involved in examples like the Ta-Ta-Ta-Taaaam) count as auditory temporal mental imagery.

Temporal mental imagery is early perceptual processing that is not triggered by temporally corresponding sensory stimulation in the relevant sense modality. In other words, temporal mental imagery is perceptual processing that comes either too late or too early compared to the sensory stimulation. Some expectations count as temporal mental imagery whereby the perceptual processing comes before the expected sensory input (and in this sense it is not triggered by temporally corresponding sensory input).

One example is the recently discovered time-compressed wave of activity in the primary visual cortex. This only happens if there is a familiar sequence of sensory events (whereby sensory inputs follow each other predictably and in a way that has been entrenched by past experiences). On the trigger of the beginning of this sequence, there is time-compressed activity in the primary visual cortex (Ekman et al 2017). This is quite literally perceptual processing (and very early perceptual processing) that is not triggered by temporally corresponding sensory stimulation in the relevant sense modality. The primary visual cortex is activated in a way that would correspond to the sensory input that is most likely to come in the next milliseconds.

Another well-researched example of expectations as mental imagery comes from pain research. Pain very much depends on our expectations (Goffaux et al. 2007; Koyama et al. 2005; Atlas and Wager 2012; see also Peerdeman et al. (2016) for a meta-analysis) and there is more and more data on the neural mechanism of this process (Sawamoto et al. 2000; Keltner et al. 2006; Ploghaus et al. 1999; Jensen et al. 2003).

One crucial finding is about the sensory cortical areas (S1/S2). These brain regions are very early cortical areas involved in the processing of painful input very early on in cortical processing. This happens when you get a papercut – in the case of pain driven by sensory input. But also happens when you have expectations about getting a papercut – in the case of expectations of pain (Porro et al. 2002; Wager et al. 2004). In other words, Some expectations of pain will count as mental imagery in the psychological/neuroscientific sense of the term as we have clear evidence that some expectations can activate S1/S2 without any nociceptors (pain receptors) being involved (Sawamoto et al. 2000; Keltner et al. 2006; Ploghaus et al. 1999; Porro et al. 2002; Wager et al. 2004) and this amounts to early cortical pain processing that is not triggered by corresponding painful input.

It is important to emphasize that this does not mean that expectations in general will have to be labeled as mental imagery. Many instances of expectations will not count as mental imagery—for example, if I make an appointment with my dentist for next month and I am anticipating the pain I will have to endure then, this will not count as an instance of mental imagery as long as the somatosensory and anterior cingulate cortical areas are not directly activated. But we have plenty of evidence that at least some expectations can activate the somatosensory and anterior cingulate cortical areas directly, without the involvement of nociceptors (see Nanay 2017 for a summary). These instances of expectations will count as mental imagery.

Similarly for musical expectations: if I anticipate a dreadful experience at the concert tomorrow this is not necessarily a form of mental imagery (although it might be accompanied by mental imagery). But the way my mind expects a certain tone in the next split second is a form of auditory temporal mental imagery.

Take, again, the toy example of Beethoven’s Fifth. On this view, the listener forms a mental imagery of the fourth note (‘Taaam’) on the basis of the experience of the first three (‘TaTaTa’) (there is a lot of empirical evidence that this is in fact what happens – see Yokosawa et al. 2013, Kraemer et al. 2005, Zatorre and Halpern 2005, Herholz et al. 2012, Leaver et al. 2009). This mental imagery may or may not be conscious. But if the actual ‘Taaaam’ diverges from the way our mental imagery represents it (again, if it is delayed, or altered in pitch or timbre for example), we notice this divergence and experience its salience in virtue of a noticed mismatch between the experience and the mental imagery that preceded it.

The TaTaTa-Taaam example is a bit simplified, so here is a real-life and very evocative case study, an installation by the British artist, Katie Peterson. The installation is an empty room with a grand piano in it, which plays automatically. It plays a truncated version of Beethoven’s Moonlight Sonata. The title of the installation is ‘*Earth-Moon-Earth (Moonlight Sonata Reflected From The Surface of The Moon*’ (2007). Earth-Moon-Earth is a form of transmission (between two locations on Earth), where Morse codes are beamed up the moon and they are reflected back to earth. While this is an efficient way of communicating between two far-away (Earth-based) locations, some information is inevitably lost (mainly because some of the light does not get reflected back but it is absorbed in the Moon’s craters.

In ‘*Earth-Moon-Earth (Moonlight Sonata Reflected From The Surface of The Moon*’ (2007) the piano plays the notes that did get through the Earth-Moon-Earth transmission system, which is most of the notes, but some notes are skipped. Listening to the music the piano plays in this installation, if you know the piece, your auditory mental imagery is constantly active, filling in the gaps where the notes are skipped.

**IV. Multimodal perception and multimodal mental imagery when listening to music**

There is a lot of recent evidence that multimodal perception is the norm and not the exception – our sense modalities interact in a variety of ways (see Spence & Driver 2004, Vroomen et al. 2001, Bertelson and de Gelder 2004 for summaries). Information in one sense modality can influence and even initiate information processing in another sense modality at a very early stage of perceptual processing.

A simple example is ventriloquism, which is commonly described as an illusory auditory experience influenced by something visible (Bertelson 1999). It is one of the paradigmatic cases of crossmodal illusion: We experience the voices as coming from the dummy, while they in fact come from the ventriloquist. The auditory sense modality identifies the ventriloquist as the source of the voices, while the visual sense modality identifies the dummy. And, as it often happens in crossmodal illusions, the visual sense modality wins out: our (auditory) experience is of the voices as coming from the dummy.

But there are more surprising examples: if there is a flash in your visual scene and you hear two beeps during the flash, you experience it as two flashes (Shams et al. 2000). Importantly, from our point of view, early cortical processing in one sense modality can be triggered, in the absence of sensory stimulation in this sense modality by crossmodal influences from another sense modality (Hertrich et al. 2011, Pekkola et al. 2005, Zangaladze et al. 1999, Ghazanfar & Schroeder 2006, Martuzzi et al. 2007, Calvert et al. 1997, James et al. 2002, Chan et al. 2014, Hirst et al. 2012, Iurilli et al. 2012, Kilintari et al. 2011, Muckli & Petro 2013, Vetter et al. 2014). These are *bona fide* examples of perceptual processing that are not triggered by corresponding sensory stimulation in this sense modality.

When I am looking at my coffee machine that makes funny noises, I perceive this event by means of both vision and audition. But very often we only receive sensory stimulation from a multisensory event by means of one sense modality. If I hear the noisy coffee machine in the next room, that is, without seeing it, then the question arises: how do I represent the visual aspects of this multisensory event?

I argue that in cases like this one, we have multimodal mental imagery: perceptual processing in one sense modality (here: vision) that is triggered by sensory stimulation in another sense modality (here: audition). Multimodal mental imagery is not a rare and obscure phenomenon. The vast majority of what we perceive are multisensory events: events that can be perceived in more than one sense modality – like the noisy coffee machine. In fact, there are very few events that are not multisensory in this sense. And most of the time we are only acquainted with these multisensory events via a subset of the sense modalities involved – all the other aspects of these multisensory events are represented by means of multimodal mental imagery.

In discussing music, I will focus on the interplay between the auditory and the visual sense modalities. Listening to music is systematically (and often in an aesthetically relevant manner) influenced by the visual input. A lot of research has focused on how the emotional salience of the visual input influences the perception of music (see Davidson 1993, Bergeron and Lopes 2009 for summaries). Instead, I want to talk about how visual input can and often does influence our perception of musical form.

Information in the visual sense modality often highlights or emphasizes the auditory experience of musical form. One simple example of this is the conductor’s hand movements that emphasize and highlight certain formal elements of music. Nicolaus Harnoncourt’s conducting, with his usually economical movements that only burst into gestures at formally significant points, provides an excellent example. Most of the time, he merely dictates the rhythm – like many other conductors. But occasionally, when something important is happening in the score, he suddenly bursts into an energetic gesture that draws our (visual) attention to what is going on in the musical score at that moment, thereby making the musical form more salient.

Other examples where vision highlights and emphasizes musical form includes some ballet and modern dance choreographies, for example ones by Mark Morris or Jiri Kylian. Both of these choreographers tend to adjust their choreography to the music in a (sometimes almost comically) synchronous manner. Take Jiri Kylian’s choreography ‘Birthday’ for the Nederlands Dans Theater (2006) that uses the music of Mozart’s Ouverture of *Le Nozze di Figaro*. Everything the two dancers do in the kitchen (sneeze, cut the dough, break eggs, etc) is synchronous with the most important musical features – this often leads to comical effects. This choreography makes the musical features that are accompanied by synchronous visual impulses much more salient.

But vision does not always serve to emphasize and highlight musical form. Often, it does the exact opposite: it serves as a counterpoint. Take the famous performance of Rameau’s *Les Indes Galantes* by Les Arts Florissants, conducted by William Christie and choreographed by Blanca Li and Andrei Serban (2004, Opera National de Paris). The choreography of the duet ‘Forêts paisibles’ in the last act between Zima and Adario involves very pointed visual gestures against the beat, which makes our multimodal experience of this performance of the duet shift time signature. We hear it as having the time signature of 4/4 instead of the original *alla breve* time signature (2/2) as prescribed in Rameau’s score. Here what we see (gestures against the beat) makes us experience the formal properties of the music differently.

To turn to modern dance, some of Pina Bausch’s choreographies use the same effect. At the beginning of her *Café Müller* (1978, Tanztheater Wuppertal), the woman’s movements almost always seem to be the exact opposite of what is happening in the musical score (of ‘O let me weep’ from Purcell’s *The Fairy Queen*). She stands still for a long time and then suddenly, when there is a lull in the music, starts running; she makes frantic complicated gestures while the music is slower and hardly moves when the music gets faster. The same applies to Bausch’s choreography for Gershwin’s ‘The man I love’ in her *Nelken* (1982, Tanztheater Wuppertal), where the man’s gestures are supposed to express the same meaning as the song’s lyrics, but their timing is almost always against the beat. In this interesting example, the auditory experience of both the musical form and the expressive content is influenced by visual effects (see Nanay 2012 for more examples of this kind).

All of these examples are examples of multimodal perception of music. But if you experience one of the performances described in the last four paragraphs, your next encounter with this piece of music will be colored by your multimodal mental imagery. Take the example of Rameau’s *Les Indes Galantes* by Les Arts Florissants. If you watch the duet ‘Forêts paisibles’ in the last act between Zima and Adario and then, a couple of days or weeks later you listen to the music alone, because of your prior experience of the visual input against the beat, you will have visual imagery in those moments (influenced by your past experience).

And this multimodal mental imagery has a significant influence on your musical experience (of the music only). Importantly, it will make your experience (of the music only) have the time signature of 4/4 instead of the original *alla breve* time signature (2/2) as prescribed in Rameau’s score.

You may say that when you listen to the music and you introspect, you don’t feel any multimodal mental imagery. It should be clear from the discussion of mental imagery in general and multimodal mental imagery in particular in the first half of this paper that mental imagery does not have to be conscious and it is, in fact, most often unconscious. The same goes for the multimodal mental imagery that plays a role in our perception of music. Even though you are not aware of the multimodal mental imagery when listening to the Rameau duet, your visual cortices are nonetheless active and they also actively influence your auditory cortices in those moments that correspond to the gestures against the beat in the performance.

In fact, multimodal mental imagery here works in a fairly complex manner. The auditory sensory stimulation (of listening to the duet) triggers the visual mental imagery of the gestures against the beat, which in turn influence the auditory processing and musical expectations, which then influence even global characteristics of the musical experience as musical meter. The overall conscious musical experience will be different, but none of these ingredients need to be conscious. Multimodal mental imagery often works under the radar, but its impact is nonetheless very significant on the overall musical experience.

**V. Conclusion**

Some purists try to screen out all non-auditory stimulus when listening to music – they close their eyes, for example. This is a mistake, because given the deep multimodality of perception, the multimodal aspects of music perception can enrich our music perception. I gave some examples in the last section of how this could happen (see also Nanay 2015, 2016).

The importance of multimodal mental imagery highlights just how crucial these multimodal aspects are or at least can be. Your multimodal perception of a musical piece even just once can significantly alter not just that one experience, but all your experiences of this piece in at least the near the future. You are likely to be stuck with the specific multimodal mental imagery after that one instance of listening.

This can be and often is a good thing. But it is also potentially dangerous. Just as listening to one bad performance of a musical piece can have a negative impact on all your subsequent experiences of this piece (because it triggers the wrong kind of musical expectations), listening to a performance of a musical piece with the wrong or distracting multimodal input can also have a negative impact on your subsequent listening, because it will evoke the wrong or distracting multimodal mental imagery.

Multimodal mental imagery evoked in musical listening is aesthetically relevant. But aesthetic relevance can have a positive or a negative valence. Our expectations are malleable, and our multimodal expectations are even more malleable. Again, this can be a good thing or a bad thing. This means that the conclusion of this paper is not merely of academic importance. It is an important warning to all of us about paying extra attention to how we listen to music.[[1]](#footnote-1)

**References:**

Atlas, L.Y. and T. D. Wager 2012. “How Expectations Shape Pain,” *Neuroscience Letters* 520: 140–48.

Bergeron, V. and D. Lopes, 2009 ‘Hearing and seeing musical expression’, *Philosophy and Phenomenological Research* 78: 1–16;

Bertelson, P. (1999) Ventriloquism: A case of cross-modal perceptual grouping. In: Aschersleben, G., Bachmann, T., and M¨ usseler, J. (eds): *Cognitive Contributions to the Perception of Spatial and Temporal Events*, Amsterdam: Elsevier, pp. 347–362.

Bertelson, P. and de Gelder, B. (2004) The psychology of multimodal perception. In Spence, C. and Driver, J. (eds): *Crossmodal Space and Crossmodal Attention*, Oxford: Oxford University Press, pp. 141–177.

Calvert, G. A., Bullmore, E. T., Brammer, M. J., Campbell, R., Williamns, S. C. R., McGuire, P. K., Woodruff, P. W. R., Iversen, S. D. & David, A. S. 1997 Activation of auditory cortex during silent lipreading. *Science* 276: 593-596.

Chan, J. S., van den Bosch, J. J. F., Theves, S., Hardt, S., Pflanz, P., Lotsch, J., Kaiser, J. and Naumer, M. J. 2014 Synaesthesia or vivid imagery? A single case fMRI study of visually induced olfactory perception. *Multisensory Research* 27: 225-246.

Davidson, Jane W. 1993 ‘Visual Perception of Performance Manner in the Movements of Solo Musicians’, *Psychology of Music* 21: 103–12.

Ekman, M. P. Kok and F. P. de Lange 2017 Time-compressed preplay of anticipated events in human primary visual cortex. *Nat. Commun.* 8,15276 doi: 10.1038/ncomms15276.

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

Goffaux, P., W.J. Redmond, P. Rainville, and S. Marchand 2007. “Descending Analgesia—When the Spine Echoes What the Brain Expects,” *Pain* 130: 137–43.

Goodale, M. A. and A. D. Milner 2004 Sights Unseen. Oxford: Oxford University Press.

Herholz, S. C., Halpern, A. R., & Zatorre, R. J. (2012). ‘Neuronal correlates of perception, imagery, and memory for familiar tunes.’ *Journal of cognitive neuroscience*, 24(6), 1382-1397.

Hertrich, I., Dietrich, S., & Ackermann, H., 2011. Cross-modal interactions during perception of audiovisual speech and nonspeech signals: an fMRI study. *Journal of Cognitive Neuroscience*, 23, 221-237.

Hirst, P., Khomami, P. J., Gharat, A. & S. Zangenehpour 2012 Cross-modal recruitment of primary visual cortex by auditory stimuli in the nonhuman primate brain: A molecular mapping study. *Neural Plasticity* 2012: 197264, doi:10.1155/2012/197264

Iurilli, G., D. Ghezzi, U. Olcese, G. Lassi, C. Nazzaro, R. Tonini, V. Tucci, F. Benfenati and P. Medini 2012 Sound-driven synaptic inhibition in primary visual cortex. *Neuron* 73: 814-828.

James, T. W., Humphrey, G. K., Gati, J. S., Servos, P. Menon, R. S. & Goodale, M. A. 2002 Haptic study of three-dimensional objects activates extrastriate visual areas. *Neuropsychologia* 40: 1706-1714.

Kentridge, R.W., Heywood, C.A., and Weiskrantz, L. (1999). Attention without awareness in blindsight, *Proc. R. Soc. Lon. B*, 266: 1805-1811

Kilintari, M., Raos, V., & Savaki, H. (2011). Grasping in the dark activates early visual cortices. *Cerebral Cortex*, 21, 949–963.

Kosslyn, Stephen M., Thompson, William L. and Ganis, Giorgio (2006) *The Case for Mental Imagery*. Oxford: Oxford University Press.

Kouider, S., & S. Dehaene. 2007. Levels of processing during non-conscious perception: A critical review of visual masking. *Philosophical Transactions of the Royal Society B* 362: 857-875.

Koyama, T., J.G. McHaffie, P.J. Laurienti, and R.C. Coghill 2005. “The Subjective Experience of Pain: Where Expectations Become Reality,” *PNAS* 102: 12950–55.

Kraemer, D. J. M., Macrae, C. N., Green, A. E. & Kelley, W. M. (2005). ‘Musical imagery: Sound of silence activates auditory cortex.’ *Nature* 434: 158.

Krumhansl, C. L., & Schenck, D. L. (1997). Can dance reflect the structural and expressive qualities of music? A perceptual experiment on Balanchine’s choreography of Mozart’s Divertimento No. 15. *Musicae Scientiae, 1,* 63–85.

Leaver, A. M., Van Lare, J., Zielinski, B., Halpern, A. R., & Rauschecker, J. P. (2009). ‘Brain activation during anticipation of sound sequences.’ *The Journal of Neuroscience*, 29(8): 2477-2485.

Martuzzi, R. Murray, M. M., Michel, C. M., Thiran, J-P., Maeder, P. P., Clarke, S. & Meuli, R. A. 2007 Multisensory interactions within human primary cortices revealed by BOLD dynamics. *Cerebral Cortex* 17: 1672-1679.

Muckli, L., & Petro, L.S. (2013). Network interactions: non-geniculate input to V1. *Current Opinion in Neurobiology*, 23, 195–201.

Nanay, Bence 2012 The multimodal experience of art. British Journal of Aesthetics 52: 353-363.

Nanay, Bence 2015 Perceptual content and the content of mental imagery. *Philosophical Studies* 172: 1723-1736.

Nanay, Bence 2016 *Aesthetics as Philosophy of Perception*. Oxford: Oxford University Press.

Nanay, Bence 2017 Pain and mental imagery. *The Monist* 100: 485-500.

Nanay, Bence 2018 Multimodal mental imagery. *Cortex* 105: 125-134.

Nanay, Bence forthcoming *Mental Imagery*. Oxford: Oxford University Press.

Pearson, Joel, Thomas Naselaris, Emily A. Holmes, and Stephen M. Kosslyn 2015 Mental Imagery: Functional Mechanisms and Clinical Applications. *Trends in Cognitive Sciences* 19: 590-602.

Pekkola, J., Ojanen, V., Autti, T., Jaaskelainen, I.P., Mottonen, R., Tarkainen, A. & Sams, M. 2005 Primary auditory cortex activation by visual speech: an fMRI study at 3 T. *NeuroReport* 16: 125-128.

Peerdeman, K.J., A.I. van Laarhoven, S.M. Keij, L. Vase, M.M. Rovers, M.L. Peters, and A.W. Evers 2016. “Relieving Patients’ Pain with Expectation Interventions: A Meta-Analysis,” *Pain* 157: 1179–91.

Sawamoto, N., M. Honda, T. Okada, T. Hanakawa, M. Kanda, H. Fukuyama, J. Konishi, and H. Shibasaki 2000. “Expectation of Pain Enhances Responses to Nonpainful Somatosensory Stimulation in the Anterior Cingulate Cortex and Parietal Operculum/Posterior Insula: An Event-Related fMRI Study,” *Journal of Neuroscience* 20: 7438–45.

Shams, L., Kamitani, Y., and Shimojo, S. 2000 What you see is what you hear. *Nature* 408: 788.

Vetter P., Smith F. W., Muckli L. (2014). Decoding sound and imagery content in early visual cortex. *Current Biology* 24: 1256–1262.

Vroomen, J., Bertelson, P., and de Gelder, B. (2001) Auditory-visual spatial interactions: Automatic versus intentional components. In: de Gelder, B., de Haan, E., and Heywood, C. (eds): *Out of Mind*, Oxford: Oxford University Press, pp. 140–150.

Watkins, S., Shams, L., Tanaka, S., Haynes, J. D., and Rees, G. 2006 Sound alters activity in human V1 in association with illusory visual perception. *NeuroImage* 31: 1247-1256.

Weiskrantz, L. 2009. *Blindsight: A Case Study Spanning 35 Years and New Developments*. 2nd Edition. Oxford: Oxford University Press.

Yokosawa, K., Pamilo, S., Hirvenkari, L., Hari, R. & Pihko, E. (2013). ‘Activation of auditory cortex by anticipating and hearing emotional sounds: an MEG study.’ *PLoS ONE* 8(11): e80284.

Zangaladze, A., Weisser, V. D., Stilla, E., Prather, S. C. & Sathian, K. 1999 Involvement of visual cortex in tactile discrimination of orientation. *Nature* 401: 587-590.

Zatorre, R. J. and Halpern, A. R. (2005). ‘Mental concert: Musical imagery and auditory cortex.’ *Neuron* 47: 9-12.

1. This work was supported by the ERC Consolidator grant [726251] and the FWO research grant [G0C7416N]. Special thanks for comments by the two referees, Adriana Renero and Tom Cochrane. [↑](#footnote-ref-1)