The pleasure of reading

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Pleasure is central to life. While many species share some of the same brain networks for pleasure, there are clearly species-specific routes to pleasure, of which language and music are among the most important in humans. Reading and writing are very useful interfaces to these temporal human pleasures, which allow us to communicate, record, experience and imagine the hedonic experiences of other humans across time and space. While we have yet to fully understand the underlying neural mechanisms of language and music, there is now evidence from brain science which can help to elucidate some of the relevant functional neuroanatomy. Here, we review our still rather limited understanding of reading and pleasure seen from a brain perspective and note that while this approach is obviously still limited in scope, it might nevertheless offer new and interesting insights. In particular, we try to synthesise the current evidence from brain science to propose a novel model of how reading may come to evoke subjective hedonic experience. We highlight the central role of anticipation and how this might provide a key to how the brain works on many different levels, including the capacity of reading to evoke pleasure.

INTRODUCTION

Pleasure is intimately linked to emotional and reward processing in the brain (Berridge and Kringelbach, 2008; Kringelbach, 2008b) and must serve a central role in fulfilling the evolutionary imperatives of survival and procreation (Darwin, 1872).

Pleasure is not a sensation but is instead linked to the anticipation and subsequent evaluation of stimuli. Pleasure is thus a complex psychological phenomenon with close links to the reward systems of the brain and as such consists of both conscious and non-conscious processing. In this sense, pleasure is similar to any other human experience where learning is involved.

Pleasure can be classified into *fundamental* and *higher-order pleasures* (Berridge and Kringelbach, 2008). The fundamental pleasures include the sensory pleasures which are clearly linked to food intake as well as sex (Berridge, 1996; Kringelbach, 2004). In addition, social interactions with conspecifics are common to both survival and procreation, and in social species, such as humans, it is likely that the social pleasures are part of the fundamental pleasures (Kringelbach *et al.*, 2008).

With the appropriate experimental paradigms it is thus possible to study the brain regions and brain mechanisms of the fundamental pleasures in both humans and other animals, while the higher-order pleasures can perhaps only be studied in people using

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scientific tools such as neuroimaging. The scientific study of pleasure has revealed that there are at least three fundamental elements to pleasure: wanting, liking and learning (Kringelbach and Berridge, 2008).

The higher-order pleasures include monetary, artistic, musical, altruistic and transcendent pleasures, and have previously been proposed as species-specific routes to the brain networks subserving the fundamental pleasures (Kringelbach, 2008a). It remains possible, however, that higher-order pleasures are different in kind rather than degree from the fundamental pleasures (Changeux, 1994).

In the following we will focus on the pleasure of reading, which is an example of a higher-order pleasure likely unique to humans. Reading acts as an interface to both language and music. Some people might argue that language and music would seem to have very different trajectories, the one toward abstraction, the other toward sensuousness and emotion. Yet, the scientific evidence has shown that they are perhaps more alike than different (Patel, 2008). They both elicit such deep pleasures that most people consistently rate them very highly. Yet it is remarkable how little is known about the underlying neural mechanisms of language and music (Hauser, 1996; Vuust and Kringelbach, 2008), despite neuroimaging studies of their similarities (Brown *et al.*, 2006).

The bulk of the scientific evidence suggests that language is probably unique to humans (Hauser, 1996). Uniqueness is more controversial for music, since other animals are clearly capable of hearing the sounds. However, they appear unable to take pleasure in music (McDermott and Hauser, 2007). There are clearly differences between the brain regions participating in visual and auditory decoding of language and music perception (Griffiths, 2001; Hauser and McDermott, 2003) and differences in the subsequent emotional processing and pleasure evoked (Blood and Zatorre, 2001b; Blood *et al.*, 1999; Green *et al.*, 2008; Griffiths *et al.*, 2004).

Anecdotally, some animals take pleasure in moving to the rhythm of music, which seems evident when watching the dancing cockatoo 'Snowball' on youtube.com. Scientific studies of animals (including non-human primates) have, however, consistently failed to show any sort of pleasure or displeasure related to music-like activity or perception (Bates and Horvath, 1971; Hauser and McDermott, 2003; Steele, 2006), although there is recent evidence that music can act in conjunction with other cues as a significant aversive noisy stressor even in rats (Reynolds and Berridge, 2008). While studies of our closest cousins have shown that some of the basic abilities underlying music perception, such as octave recognition, may be in place (Hauser and McDermott, 2003), monkeys are unaffected by dissonance and consonance (McDermott and Hauser, 2004) and do not appear to take pleasure in music overall (McDermott and Hauser, 2007).

Here we are going to concentrate on visual decoding (reading) rather than auditory decoding (hearing). The mechanics of reading single words have been described in quite a lot of detail. Apart from a series of studies using a visuo-musical, attentional interference task, Stewart and colleagues demonstrated that music reading recruits brain areas related to spatial sensorimotor mapping and involves the automatic sensorimotor translation of a spatial code (Stewart, 2005; Stewart *et al.*, 2003a, b; Stewart *et al.*, 2004). Nevertheless, sight reading of music is still relatively unexplored. Crucially, however, much less is known about the processing allowing us to read and extract meaning and pleasure from sentences and paragraphs.

We will therefore concentrate on describing the brain mechanisms of reading single words but note that similar principles are likely to underlie sight reading of music. We review the current state-of-the-art in the separate fields of reading and pleasure research, followed by speculations about the potential neural mechanisms for the pleasure of reading, and in particular the role of anticipation.

THE FUNCTIONAL NEUROANATOMY OF READING

Most people in the developed countries are expert readers, but it is somewhat of an enigma that our brain can achieve expertise in such a recent cultural invention. Given that the first alphabetic scripts were only invented probably around four to five thousand years ago and thus only after Homo Sapiens sapiens had fully evolved, evolution has not had time to develop specialised parts of the brain for reading. Instead, reading is possibly the most important example of how brain functions can be recycled (Dehaene, 2005), in a similar way to exaptation of evolutionary function (Gould and Vrba, 1982). In other words, reading is a prime example of how culture can shape the brain (Cornelissen *et al.*, 2009).

Reading depends intimately on our ability to visually decode words. Consider the large variation in fonts, or the even greater variation between a typographic font and handwriting. In addition, consider the difference between words written only in CAPITALS and those written in a mixture of LoWErCASe and uPPeRcASE letTeRs. Despite the difference, we are quickly able to reduce these visual impressions to meaningful words (Hofstadter, 1995). We are even aware of small changes in words that look similar, but have very different meanings, such as ‘read’ and ‘reap’.

Over the last couple of years, neuroimaging and neuropsychological experiments have demonstrated that reading takes over regions of the brain that would otherwise have other uses. This repudiates the previous claims of some researchers that the brain is capable of learning anything – that it is a blank sheet upon which anything can be written.

Quite to the contrary, we now know that the brain’s learning possibilities are limited by our evolutionary history and the challenges that our common ancestors faced. Certain parts of the brain are specialised for the processing of one kind of sensory input and not other kinds. In only very few cases can these areas be used for the processing of other sensory inputs (Büchel *et al.*, 1998). This means that flexibility of learning is often only possible in higher association areas and only to the extent that this new ability is related to the function of the existing region.

Reading is a complex skill that depends on the activity of many different functional brain areas spread over the whole brain. Words have to be recognised, and meaning has to be derived and integrated in longer sentences that allow us to pronounce the words and sentences (Kujala *et al.*, 2007). We are only slowly beginning to understand the details of how this process works, and how it relies both on bottom-up and on top-down processes (Dehaene, 2007). We have gained understanding of the function of a region in the fusiform cortex on the underside of the brain between cortex and cerebellum. The region has been called the visual word form area and is a part of the visual regions that let us recognise objects (Cohen *et al.*, 2000).

The visual word form area appears to play a specific role in the early stages of reading in that it is only activated by visual words, and not, for example, by spoken words. In addition, this area seems to trigger the same amount of activity whether the person is reading real or pseudo words. Pseudo words are words such as 'lyve' or 'ryne' that follow the phonetic rules of English, so they are easy to pronounce, but are not found in the dictionary

So it would appear that the visual word form area plays a more important role in decoding the visual form of a word rather than, for example, its meaning. People with lesions to this part of the brain are not able to read words at normal speed, but are sometimes able to decode the word, letter by letter (Epelbaum *et al.*, 2008). Paradoxically, these patients are sometimes fully capable of writing words, which they subsequently find very difficult to read again. They seldom have problems with hearing and understanding words, and are fully able to identify other visual objects such as faces or buildings.

WHAT'S IN A WORD?

Giving an adequate definition of a word is surprisingly difficult. It is clear that a word has to contain letters from the alphabet used by the given language. As part of our mental development as children, we learn language and how to discern the words of the language. A bit later in development, we learn to read and write, and to decode and encode sounds from and to visual forms. Some ancient cultures, such as the Egyptians, chose to write with hieroglyphs in which, in its most simple form, every word corresponds to a visual shape, a hieroglyph. But having to learn all the visual shapes makes such a system impractical and time-consuming in terms of brains learning to read and write. So new shapes were constructed as combinations of existing hieroglyphs. Several thousand years ago, someone had the excellent idea of inventing the alphabetical script, which allows a given language to be written from very few fundamental forms that can be combined to create the phonetic sound of a word.

How visual shapes become words depends on the culture. Japanese consists of a number of different writing systems of which the most important are Kanji and Kana. These writing systems differ in a number of ways, but mainly in that Kanji consists of symbols and Kana consists of letters. Despite the difference in forms, some evidence suggests that the visual word region is present in the same part of the brain across cultures, although this remains controversial (Nakamura *et al.*, 2005). This suggests that although we are not born with brain regions that specialise in reading, regardless of culture, we use the same brain regions when we learn to read, although the specific usage of any particular region might be culture-dependent. For example, a neuroimaging study of Chinese dyslexics showed reduced neural activation and grey matter density in frontal regions but not in the visual word form area (Siok *et al.*, 2008). This compares to studies showing that musicians employ quite different brain areas than non-musicians when processing even very simple forms of auditory input, music or language (Musacchia *et al.*, 2007; Vuust *et al.*, 2005).

The visual word form area becomes active whenever we see words, whether they are presented in the left or right part of the visual field. This area is equally active regardless of the words' case (lower- or uppercase letters) or font. So it has been suggested that the visual word form area represents the invariant visual form of a word (Cohen *et al.*, 2000).

The evidence comes from experiments using subliminal priming techniques in which words are presented for such brief intervals that participants are not conscious of having seen them. If a lowercase word such as 'bear' is presented for around 33 milliseconds, followed by the same word in uppercase shown for significantly longer time, such as 300 milliseconds, the reaction time in a lexical-decision task is usually significantly reduced compared to if an unrelated word (e.g. 'loss') is used as a prime. This is called the repetition priming effect. Words such as 'bear' and 'BEAR' look very different because of the different shapes of some lower- and uppercase letter. Our capacity of perceiving the same word in any form can only be a result of learning. Neuroimaging experiments have found activity related to the repetition priming effect in the visual word form area, which suggests that this region could represent the invariant form of the word (Dehaene *et al.*, 2001).

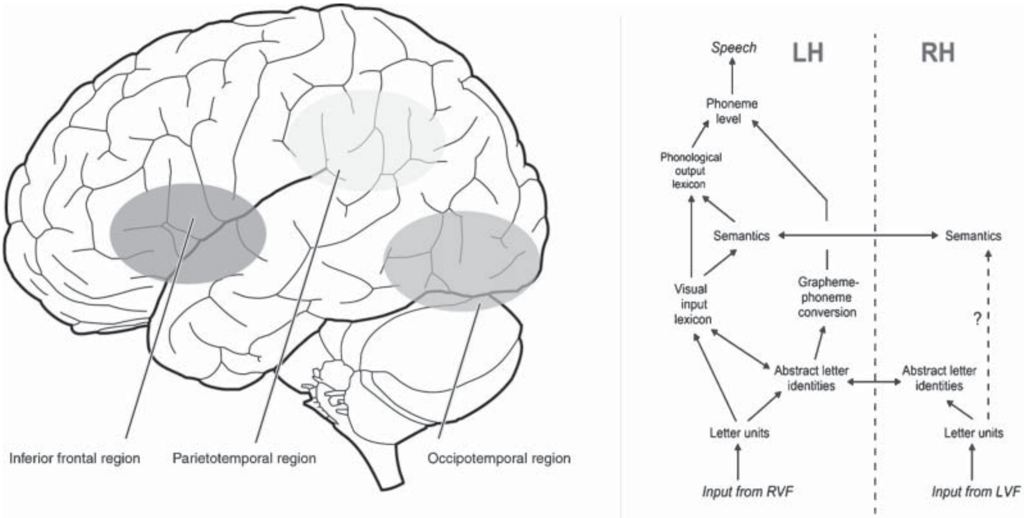
If this turns out to be true, it would be interesting to investigate what this region of the brain might do in those who have not yet learned to read, are learning to read, or have never learned to read. Although illiterates are unfortunately common in developing countries, it is difficult to find illiterates in the West who have never been exposed to words. Immigration laws conspire to make it difficult and expensive to study these groups with brain scanners.

Instead, a more feasible way to understand the development of reading is to study children who are learning to read. It has been shown that the visual word form area and nearby regions show an increase of activity as reading ability increases, so it has been named the 'skill zone' (Pugh *et al.*, in press).

Reading does not rely on activity solely in the visual word form area, but rather in a whole network of connected brain regions. The activity begins in the primary visual cortices and quickly spreads ventrally and dorsally to more anterior regions of the brain. This spreading wave of activity appears to code for increasingly abstract attributes of the visual input. A likely scenario is that of a serial decoding process in which lines of different orientation become letters that then become words that are recognised as real words, pseudo words or non-words, just as in music where a series of individual notes becomes recognised as a melodic phrase or tune (Geake, 1997). But this process is only serial in the early stages and quickly becomes rather more complex with parallel processing of multiple spreading waves (see Figure 1).

Using magnetoencepholgraphy we have recently been able to show that a part of the prefrontal cortex called the inferior frontal gyrus appears to be active before or at the same time as the visual word form area at around 130 ms (Pammer *et al.*, 2004). This is a surprising finding given that the inferior frontal gyrus has previously been seen as part of the last steps of converting words to speech. Our results suggest that reading relies on top-down processing very early on when deciding whether a word can be pronounced or not.

This finding is related to how we learn words as infants. Our parents point and name objects for us, 'see a cat', which creates an association between an object and a series of sounds. We learn to decode the sounds that our parents make as speech and to discern the syllables and word units. In a sense, reading acts like a parasite on this system and is relying equally on both visual and auditory systems.



1 Reading networks

READING AS AN EXAMPLE OF OBJECT PROCESSING

The role of the visual form area in representing the invariant form of a word depends directly on the learning that typically occurs during childhood. This learning process can go awry in dyslexia, which ultimately manifests itself as a problem with fluent reading. This simple symptom can have many different underlying causes. These have become grouped under the convenient catch-all label of dyslexia. The causes of dyslexia are still unknown but one possible strategy might be to resolve the functional role of the visual word form area in dyslexia – and in evolutionary terms in general.

Although monkeys are generally thought to be unable to read, they are able to distinguish between different visual objects such as letters and words. Experiments using neurophysiological recordings of neural activity have shown that visual impressions are processed in different brain areas in relationship to a number of properties, such as their identity and their location in space. Similar to the object processing found in humans, dissociable brain regions in monkeys are related to the 'what' and the 'where' of visual objects. The ventral part of the fusiform cortex appears to be mostly concerned with the 'what' of object processing, while more parietal regions appear to be concerned with the 'where.'

In humans, neuroimaging experiments have shown that words and faces are typically processed in cortical regions close to the regions that process visual impressions from the fovea of the retina. In contrast, it appears that buildings are processed in the cortical areas that are close to those areas that process visual impressions from the periphery of the retina. This may be related to the way we learn about them, with buildings mostly present in the periphery of vision while words and faces mostly present in the center of our vision (Hasson *et al.*, 2002).

Neurons in these brain regions appear to have different specialisations (Tsao *et al.*, 2006). Some groups of neurons become active when parts of the face are shown, while other groups are most active when a face in profile is shown, and still others are active when the frontal face is shown. All three groups of neurons have been shown to connect to a further set of neurons that become active to the invariant properties of a face. That means that this activity is not dependent on factors such as the portion, size, or viewing position of the object. So it has been proposed that a hierarchy of neurons exists in which the processing becomes ever more abstract, such that neurons at the top of the hierarchy represent the identity of an object.

Given enough time and training, most people are able to become experts at quickly distinguishing between similar visual objects. Many people know and love the series of children books in which the game is to find Wally in his red and white-striped clothes among a lot of people. Because children are remarkably quick to learn to find Wally, many people consider this ability trivial.

But finding Wally is a remarkably complicated task that we have yet to develop good computer algorithms to solve except in very simple cases. It is remarkable that tasks such as finding Wally would appear more difficult for computers than playing chess.

Learning to spot Wally shares many properties with learning to read. It is likely that one or more areas of your brain will respond maximally when you see Wally and not when you see words. These areas may well represent the invariant form of Wally, so they are a direct function of learning. Both words and Wally are processed in those brain areas that have access to the central part of our visual impressions. Both types of objects depend on already existing brain areas whose spatial placement and extent may be partly determined by genetic influences. So, for example, the visual word form area is invariably close to areas that are concerned with early visual processing and would not be expected to be found in the frontal parts of the brain. This is why we are limited in what we can learn and in the possible variations of behavior. We are unable to learn to see infrared light because our sensory receptors and brain have not evolved to sense it.

This also means that we can now explain why children always go through a phase in which they write letters such as w and m upside down and mirrored, and why they find it difficult to distinguish between the lowercase letters: p, q, b, and d. These letters are mirrored and rotated variations of each other. Our visual system is very good at reducing this variance and to recognise the letter as variations of just one invariant form. But this is not helpful in reading, so children have to learn to explicitly fight this tendency and learn to see the letters as different shapes.

So reading is a good example of cultural learning that we can hope to improve with a better understanding of the underlying brain processes. But better learning strategies will need a better understanding of the pleasures, desires, and emotions that are crucial to ensure the necessary motivation for learning. By itself reading can elicit deep pleasure and thus provide part of this motivation. A good example of this is provided by young children who teach themselves to read (Geake, 2006), with a parallel situation in music whereby young prodigies are motivated through pleasure to engage in an exacting regime of regular practice (Geake, 1996).

THE MANY FACES OF PLEASURE IN THE BRAIN

In the field of affective neuroscience a *pleasant stimulus* is often called a rewarding stimulus or simply a reward. It is useful, however, to keep in mind that actual reward lies in active processes of the brain and mind, as a reaction to a stimulus rather than the stimulus itself. Pleasure is thus never merely a sensation (Frijda, 2007).

As mentioned above, pleasure and reward may at first glance appear to be unitary processes, while they are in fact composite or complex processes containing several psychological components corresponding to distinguishable neurobiological mechanisms (Berridge and Kringelbach, 2008; Berridge and Robinson, 2003; Dickinson and Balleine, 2002; Everitt and Robbins, 2005; Schultz, 2006).

There are obviously many ways to distinguish the many faces of reward, but at the very least the major components of reward and their subdivisions include liking, wanting and learning.

Liking is the actual pleasure component or hedonic impact of a reward. Pleasure comprises two levels: (i) core 'liking' reactions that need not necessarily be conscious, (ii) conscious experiences of pleasure, in the ordinary sense of the word, which may be elaborated out of core 'liking' reactions by cognitive brain mechanisms of awareness. Interestingly, liking typically increases with repetition, which is a strong motivational factor in the learning of e.g. the complex motor skills that are crucial for developing musical abilities.

Wanting is the motivation for reward, which includes both (i) incentive salience 'wanting' processes that are not necessarily conscious and (ii) conscious desires for incentives or cognitive goals.

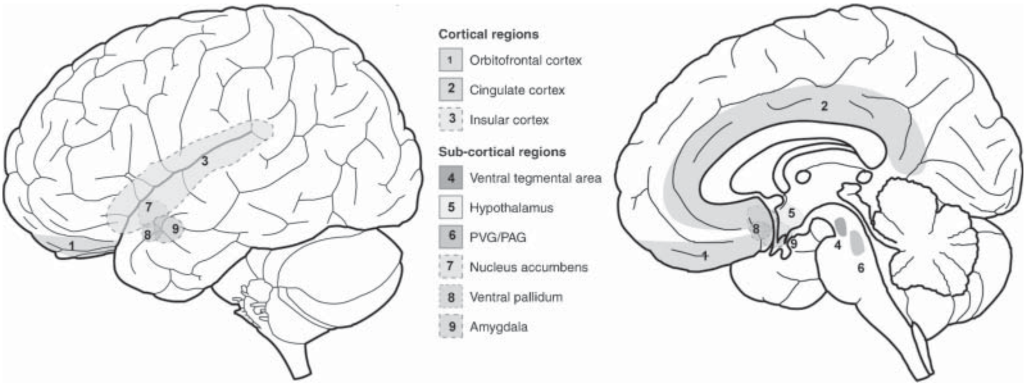
Learning comprises associations, representations and predictions about future rewards based on past experiences. Learned predictions include both (i) explicit and cognitive predictions, and (ii) implicit knowledge as well as associative conditioning, such as basic Pavlovian and instrumental associations.

Extensive research has demonstrated that these different psychological components are mediated by partly dissociable brain substrates (Berridge and Kringelbach, 2008). Within each reward component there are further subdivisions and levels, including both conscious and non-conscious processing.

The existence of multiple types of components within reward provides challenges as well as opportunities to affective neuroscientists. The primary challenge is to identify which brain systems mediate pleasure versus other components of reward, and to map components correctly onto their own neural substrates. This challenge is difficult because a rewarding stimulus or event will elicit many or all of these reward components simultaneously, and so engage many brain systems at the same time.

Further challenges can be addressed by the careful studies which are needed to tease apart whether activity in a particular brain region belongs most to the liking, wanting or learning sub-components of reward, and to understand how components are assembled by larger limbic circuits into an integrated reward system.

The opportunities and potential rewards for basic neuroscientists arise from this complexity. The challenge is to provide a richer picture of how different brain systems can play distinct roles in the composition of pleasure. Applied to psychopathology, this has important implications for understanding how a particular brain dysfunction might generate its distinct pattern of psychological disorder. In turn, that may create novel opportunities for clinical neuroscientists to move beyond 'one size fits all' therapeutic strategies, and to better allow the design of particular therapies to reverse or compensate for particular types of psychopathological dysfunction.



2 Pleasure networks

Research on humans and other animals has shown that certain networks of brain regions and neurotransmitters are essential to pleasure (Berridge and Kringelbach, 2008). Some of these regions are found deep in the brain (nucleus accumbens, ventral pallidum, amygdala, periaqueductal grey, hypothalamus and ventral tegmental area) and others in the cortex (orbitofrontal, cingulate and insular cortices) (see Figure 2).

Neuroimaging research in humans has demonstrated that higher-order pleasures such as for example music (Blood and Zatorre, 2001a) and acquisition of money (O'Doherty *et al.*, 2001) would appear to use similar brain networks as the fundamental pleasures. The question remains, however, whether the higher-order pleasure of reading language and music also recycles the same fundamental pleasure networks.

THE PLEASURE OF EXPECTANCY IN LANGUAGE AND MUSIC

The central fundamental question here is how it is possible for language and music to induce pleasure and emotions at all. Some of the common explanations fall into three categories: *1)* Language and music evoke survival-related responses connected to the way sound is processed by the auditory system, such as for example how brainstem responses to loud sounds can trigger fear responses; *2)* language and music link to some higher cognitive space that carries the particular emotion; and *3)* language and music establish, fulfil or disappoint anticipatory neural structures and mechanisms which are set up within language and music.

We have previously discussed the relative merits of each of these possible explanations with regards to music (Vuust and Kringelbach, 2008). The weight of the scientific evidence clearly points to the third explanation, namely that music expectation is a fundamental mechanism for musical experience. Language is likely to follow similar principles (Patel, 2008).

This explanation fits well with recent theories of predictive coding in the brain (Friston, 2005), which provides an account of how the brain identifies and categorises the causes of its sensory inputs (Friston, 2002; Shepard, 2001; Tononi and Edelman, 1998). Such models posit a hierarchical organisation whereby lower level brain regions estimate predictions of their expected input based on contextual information through feedback connections from higher level regions. A comparison between prediction and actual input produces an error term that, if sufficiently large, will try to force an update of the model. This generates a recursive process, which aims at minimising the difference between input and prediction. As the representational capacity of any neuronal assembly in this model is dynamic and context-sensitive, this, among other issues, addresses the problem of top-down control (Frith and Dolan, 1997; Roepstorff and Frith, 2004; Vuust *et al.*, 2008).

But how might anticipatory brain processes evoke emotion and pleasure? The weight of the current neuroscientific evidence shows that music and language share many common features (Patel, 2008). While we will concentrate on making arguments about the anticipatory features of music since the scientific evidence is stronger, many similar arguments could be made for language.

If we consider music from the viewpoint of music theory, it works by way of predictive structures in all possible layers of its structure (Vuust and Kringelbach, 2008). For example, the hierarchical structure of the meter underlies all other expectancy structures in music such as rhythm, harmony, melody and intensity, in that it influences perception of any musical event. Hence, anticipatory structures such as the meter (but also, for example, tonality) provide the listener with a framework for interpreting and remembering music.

Thus, the predictive structures in music range from simple acoustical patterns to melodic, harmonic, rhythmic hierarchical anticipatory patterns of ever greater complexity that are being established, confirmed, delayed or violated (Geake, 1997).

These anticipatory musical structures are stored in different kinds of memory systems in the brain. The predictions of how music normally develops are related to semantic memory, while veridical anticipation, i.e. predictions of music that we have heard before, is stored in long-term memory. Similarly, short-term memory is used for our memory of musical events that has occurred earlier while listening to a particular piece of music (Geake and Gregson, 1999).

Musical anticipation stimulates the brain in two basic ways that underlie our perception of the emotional content. First, anticipatory structures such as tonality and meter form the basis of memorisation and learning of musical material in that they provide the background for musical surface structure such as melody, chord changes and rhythms. Hence it is impossible to learn and remember a complex rhythm if you do not know the meter.

Second, the predictive patterns act directly on the emotional brain by way of different survival-related responses to anticipation, in particular the prediction response, which rewards predictions that have proved true in order to reinforce untried predictions. Brainstem reflexes, evaluative conditioning, emotional contagion, visual imagery and episodic memory in relation to music are all dependent on the basic anticipatory structuring of music, described above, allowing for interpretation, memory and learning.

As stated above, these predictive principles for music are very similar to those of language, which also works through continued access to memory systems. Reading acts as a gateway to the intricate processes of language (and music), and the brain processes associated with reading appear to be constantly scanning the visual input for predictive patterns, and responds strongly to deviations (Pulvermüller *et al.*, 2001).

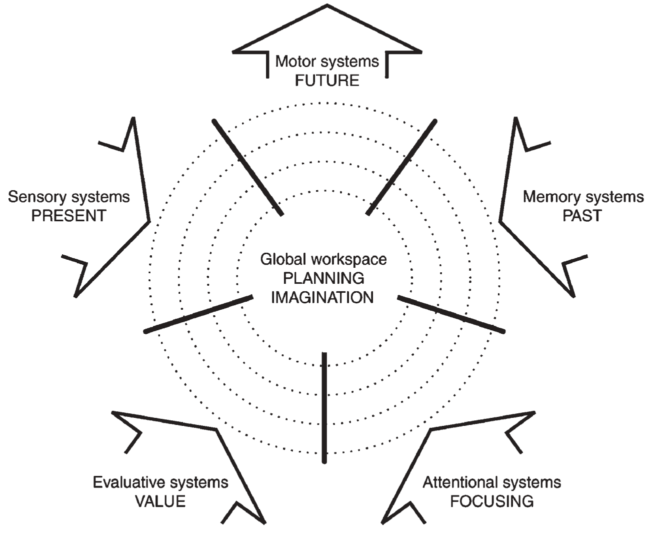
CONCLUSION

Language and music allow us to communicate, record, experience and imagine the experiences of other humans across time and space. Reading (and writing) act as less volatile decoding and encoding interfaces to the temporal pleasures of language and music, which have been with us since Homo Sapiens sapiens first evolved. However, given that the development of writing systems happened long after our species had evolved, the brain processes associated with reading must reuse existing functional brain systems and rely on learning processes.

The use of newer brain imaging techniques have allowed us to develop a detailed understanding of how single word recognition proceeds in the human brain in the first 500 ms. There is not, however, presently a similarly clear understanding of the neural activity underlying more complex decoding processes such as reading of sentences and paragraphs of text. In fact both language and music are still some of the least understood areas in terms of their functional neuroanatomy.

What is clear is that language and music are remarkably similar in their underlying organisation and that the principle of expectation is at the heart of both of them (Vuust and Kringelbach, 2008). We have previously proposed that expectation, and the more general concept of imagination, is a general organising feature of our mental lives (Geake and Kringelbach, 2007). Imaginative processes are highly distributed activities which recruit many different brain areas and networks. The complex relationships within and between these various networks is at the heart of the dynamic workspace hypothesis (Dehaene *et al.*, 1998) (Figure 3). The evaluative, memory, sensory and attentional systems provide crucial input to predict and guide internal and external change in bodily systems in the future.

The evaluative systems are thus among key factors in sustaining the life and well-being of an organism (Kringelbach, 2005). We would like to propose here that the



3 Global workspace

fundamental and higher-order pleasures and rewards could act as organising principles for brain function.

All the different emotions evoked by language and music – both positive or negative – are potentially pleasurable. Investigations of the neural underpinning of language and musical pleasure are, however, still in their infancy. Examples of this sparse research have primarily been found when studying music, such as in the two distinct responses that are widely associated with pleasure and are relatively stable: the so-called 'chills' or 'shivers down the spine' (Blood and Zatorre, 2001b; Goldstein, 1980; Panksepp, 1995; Sloboda, 1991), and the sensation of swing (Vuust *et al.*, 2006).

The hedonic evaluation of these responses to music would appear to be mediated through the reward system, and is as such related to the underlying proposed principles of expectancy. Music- and language-induced emotions are not likely: to be different from other emotions evoked by other types of biological stimuli. The decoding of both music and language rely heavily on learning, and the pleasure related to language and music decoding and performance is therefore likely ultimately to be mediated through the same fundamental pleasure and reward systems described above.

Thus, the hedonic potential of language and music is linked to the ability of language and music to help fulfill the Darwinian imperatives of survival and procreation by creating anticipation, fulfillment or violation. The pleasure obtained is subsequently attributed to language or music.

Higher-order pleasures such as reading are very important to most people. We would argue that while reading may be an accidental by-product of our species-specific object processing abilities and as such may be a higher pleasure which could be unique to humans, it is a vital pleasure that we would be foolish not to enjoy as a perfect counterpart to many of life's other sensory, sexual and social pleasures.

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