Neural Substrates of an Ongoing Musical Experience

A review of imagery studies in cognitive neuroscience and hallucination research in neurology and biological psychiatry

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Abstract

This work reviews the recent findings from cognitive neuroscience, biological psychiatry and neurology related to ongoing musical experience and attempts to reveal their possible common neural substrate. The study of mental imagery has been an expanding topic in psychology for almost three decades. The research has concentrated on the visual domain, but auditory imagery has also lately received increasing attention. Cognitive neuroscience has expanded the imagery research. Its results bespeak of a domain specific imagery that is realized in a neural substrate shared with perception. There results back up the behaviourally motivated interaction model of perception and imagery. The same model also explains well similar findings between overt and covert musical performance. There are some musical phenomena that have not been studied in psychology, like cognitive itch that is a recently coined term for a common phenomenon, which is also supposed to share neural mechanisms imagery.

In psychiatry and neurology hallucinations have long been a relevant subject. Despite the unresolved conceptual problems in defining the limits of real and so called pseudo hallucinations, very recently new light has been shed on musical hallucinations as well as on their neural substrate. Imaging studies have revealed activation patterns specific to musical hallucinations, quite similar to ones evoked by musical imagery.

Taken together results from these three disciplines support the continuum hypothesis which places perception, imagery and hallucinations to the same axis. The exact common mechanisms are not yet understood, but is suggested that one shared property would be subvocalization, a core property of auditory imagery and possibly the cause schizophrenic hallucinations. Future studies hopefully clarify the role of subvocalization, eliminate the confusion about various hallucination subtypes and set imagery relevant hypotheses that can be tested in neuroscience.

CONTENTS

0 Prologue

My primary motivation for this work has been music. Especially the music inside my head, which most us can experience when instructed to imagine the national anthem or some other familiar tune. How is it possible and how did the music get there in the first place? Let's consider the possibilities. Here's a challenge, what's the following music excerpt? If you take a look at the image below, you may not at first recognize that it represents something familiar.

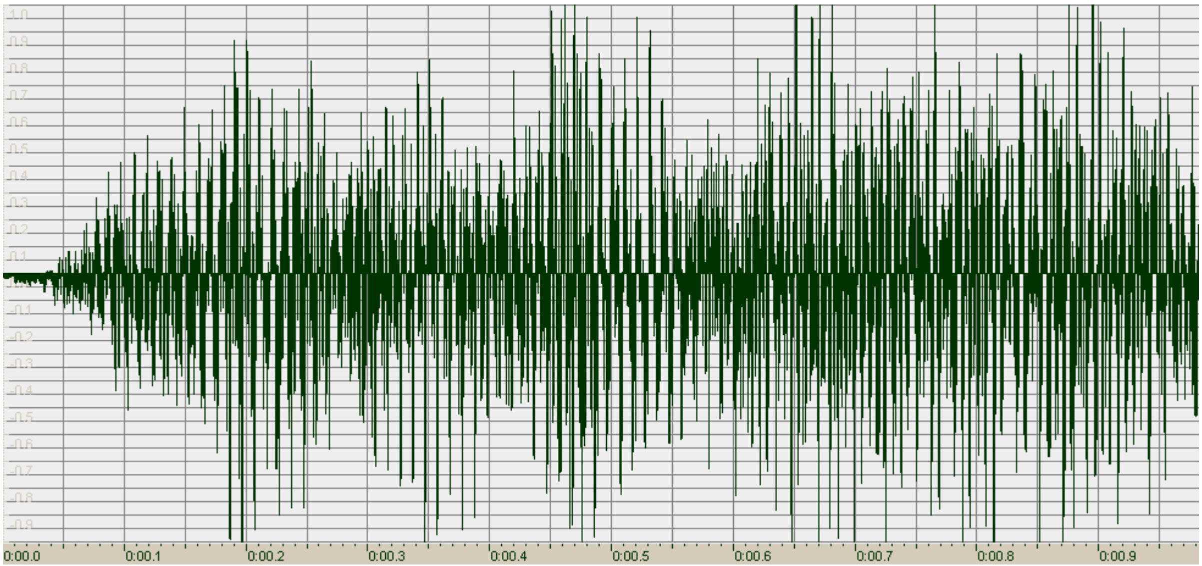


Image 1. A visualized waveform.

A visual presentation of air vibration is not quite as expressive as the real thing, is it? Still the image represents all possible data about the sound and a computer can manage this type of information, record it and reproduce it verbatim. It is able to do that because it has been programmed to do so. Could we have a same sort a recorder in our brain? The brain as an audiotape recorder model doesn't seem very tempting. I can't remember every attack and decay from national anthem nor am I able to do a visual to auditory conversion, so I assume my brain has not been wired in a same way. Let's try something more "brain friendly". Some readers maybe competent to recognize the following score below, representing the same passage:

Image 2. The opening, first bars. Sloboda (1985:185), reproduced without permission

If you can, play those notes yourself and find out the musical idea behind these visual forms. In case you need to - some people can "hear the music" even by reading the score (Brodsky et al. 2003). This tip was not easy but considerably more brain friendly than the former. So, this might be one way for the brain to store musical information, but as the appreciation of musical notation is a skill, it may not be the exactly accurate solution. Because if you happen to be musically illiterate or semiliterate, as I am, you need something else. The final hint (or there would have one more, if the medium had allowed it, but printed medium can't get us any closer to actual sound than the first analogue example did). So, the image of a waveform and the staff are showing the very famous first movement of Beethoven's Fifth symphony, one of the most popular conducted and recorded symphonies in the world. Now you may be finally able to recall the melody through your mind's ear. If that didn't ring the bell (or play the violin, to be exact), it'd suggest you should listen to this one second excerpt and experience the third type of a representation.

I have tried to demonstrate the three different types of presentations, some of them more explicit and public than the others. Musicians often like to emphasize the importance of the original presentation, the composer's idea. But, what is that? Excluding the staff, do we have any insights to the composer's internal representation of the composition, as the musical experience hopefully evoked by previous tips is private and intimate?

In this work I'll be concentrating on musical representations and attempts to unravel their neural substrates. I will present a definition of music to restrict the research area and concentrate to experience aspect and put less emphasis on music perception and reproduction.

1

Introduction

> Cognitive scientists are interested in the mental structures that underlie the experience of imagery, or mental acts in which we seem to re-enact the experience of perceiving an object when the object is no longer available.
> Halpern & Zatorre (1999:697)

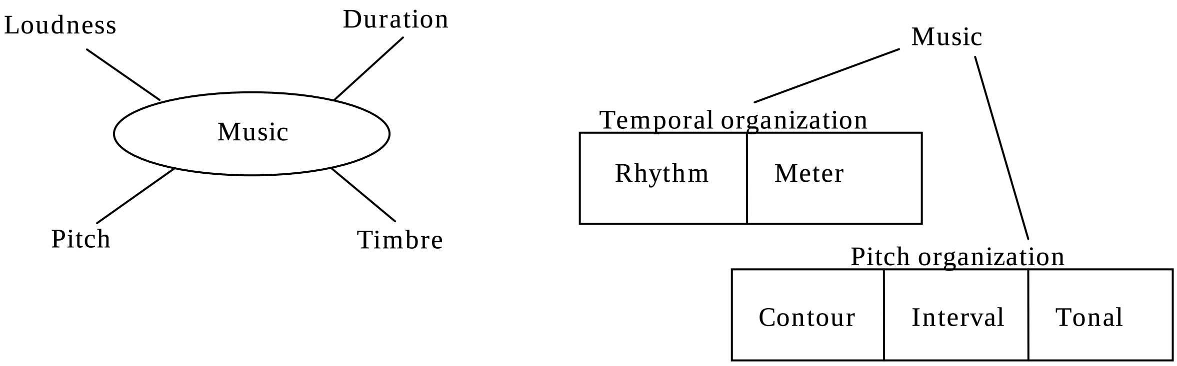
Original interest for this thesis was cognitive itch, a phenomenon in which a tune you have recently heard bounces back to your consciousness all over again no matter what you do (Kellaris 2001, 2003). As I'm not diagnosed as having a psychiatric disorder (at least not yet) I assumed that this phenomenon would have a psychological explanation. After a brief investigation I found out, that the described phenomenon has not been investigated in contemporary psychology and therefore lacks a cognitive clarification. This is probably because phenomenology and mental events, excluding emotions, have not been especially popular in mainstream cognitive psychology. The underlying reason is that the subjective reports are of limited use to assess the cognitive processes in a scientifically rigorous manner. So a review to musical experience requires different approach. There are some related subjects, musical imagery and hallucinations which have been more thoroughly explored, and will serve as a starting point.

In this review I will examine two separated research areas, one of psychology and one consisting of psychiatry and neurology, in detail and determine what conjunctions they might have. As these programs could be called paradigms, it is not wise to assume that a purely conceptual approach would find a coherence between them. So I wish to probe the empirical findings, in the form of neuroscientific results and take a "cognitive stance" in the search for neural substrate of an ongoing musical experience. Finally I approximate the relevance of findings in these two domains to the cognitive itch and its neural substrate.

To take a step towards a comprehensive review and select appropriate studies, I must provide an answer to one fundamental question; what is music? The answer is not as self-evident as one might think. Many music scientists would disagree on all but very general definitions, like the following operational definition

> Musics can be defined as those temporally patterned human activities, individual and social, that involve the production and perception of sound and have evident immediate efficacy or fixed consensual reference
> (Cross 2001:33)

This sort of a definition is far too general and vague for constraining this work. There are hundreds and hundreds of studies that would fit in this description. In cognitive science music could also be determined as a high-level pattern of temporally organized sound, where high level refers to discrimination between low level that is engaged in processing very basic properties of sound, e.g. pitch, and are supposed to have a different neural substrate (Griffiths 2000, 2001).This definition is not more helpful in constraining this study. So I selected a minimum requirement, that the music is an auditory experience containing at least recognizable melody (a pitch pattern with temporal organization, in Weinberger 1999). In principle, this rules out normal speech, environmental sounds, simple waveforms, and different noises[1]. Also tinnitus is left out, as it's a distinct, better understood phenomenon (Cacace 2003) even if it may co-occur with musical hallucinations in some occasions (Johns et al. 2000). No restrictions to the complexity of auditory experience seem necessary. This operational definition captures only some aspects of musical experience and a more elaborate analysis can reveal more components. Some suggestions on multi-component structure for music are displayed in the figure XXX. Components' independent existence is not self-evident, but there is suggestive evidence (Zatorre et al. 2002; Vignolo 2003) that they truly are distinct and modular in the brain.



A **B**

[1] This is not a definition of music but a selection criteria. Weinberger (1999) states that "[there is a] difficulty of providing definitions of sound that distinguish clearly between musical sounds and nonmusical sounds. Indeed, such a distinction may not be possible."

Figure 1. Propositions for music's component structure. Figure A according to Hubbard & Stoeckig (1988), figure b adapted from Peretz & Coltheart (2003)

1.1 Neurosciences

At present there are several specialized neurosciences and the area is ever expanding. They all share a common interest, the brain, but express it differently seeking answers to different questions. Each bears some significance to the neural substrates of musical experience but only the some essential disciplines, their methods and concepts will be introduced here.

Neuropsychology gives us information about cognitive functions relation to the brain anatomy by studying accidentally, surgically or innately damaged brains. The brain disorders affecting cognitive functions have been systematically studied since 19th century (Platel 2002). The newcomer cognitive neuroscience expands the possibilities of neuropsychology, allowing the investigation of intact and normally functioning brain and the exploration of temporal properties of brain function. Roots of neurology go deep to the history of western culture. Still the greatest progress within neurology has been done achieved during the last century. Medical interest in brain functions and abnormalities related to music can possible bring us information distinct from what could be reached in neuropsychology. Traditional psychiatry attempts to describe mental disorders and device diagnostic methods to promote proper treatments. Biological psychiatry extends this quest employing neuroscientific methods to study mental disorders, dysfunctions of an otherwise normal brain. When the symptoms include music, usually hallucinations, they give us one more approach to the study of music's neural substrate. (Kandel & Schwartz, 1985).

Combining knowledge from these domains can hopefully tell us about the neural requirements and processes, which enable us to experience music from ongoing acoustic signal or from an activation of musical memories. The term neural substrate is not explicitly defined in literature. Here I define neural correlate as a purely statistical term, linking experiment task to some specific brain activation. The neural substrate is defined as a neural correlate accompanied with a supporting theory. If the theory would be enough exact and verified, we could rename the correlate as neural basis or implementation.

The introduced neurosciences use a wide range of different techniques nowadays. Methods have distinctive properties and are classified by their spatial and temporal resolution. They usually go under an abbreviated names [2]. Results from different types of techniques are not always directly comparable, so the evidence between investigations tends to be suggestive and incommensurable.

Seeking neural substrate in a cognitively plausible way requires an approach found most explicitly in cognitive neuroscience. Studies in that domain assume that we can reliably record brain activation related to specific cognitive processes, e.g. music perception. The standard procedure is to device behavioral experiments, like the ones used in cognitive psychology, and have the participant complete the test while registering indicators of brain activation. Using statistical comparison, we can then spot the neural correlates of the cognitive processes involved in the experiment. When we observe the correlate for some process systematically in one spatial position, it is said to be localized there. Lateralization refers to a localization of a cognitive function to a specific hemisphere, e.g. language is usually lateralized to left hemisphere. Brain processes are dynamic; they take place in a temporal continuum. Processes are usually very fast compared to the temporal resolution of the research equipment. If the equipment has an adequate temporal resolution in addition to localization the temporal characteristics of brain activity can be described, reflecting an interplay between different cognitive processes (Gazzaniga et al. 1998).

1.2 Representation instances

Representations are essential to cognitive science as human brain is considered an information processing system, operating on representations. We need a representation for every mental experience, including music. Basically we have three situations in which we can expect to encounter musical representations. They are perception, imagery, and performance. In perception, the representation is heavily influenced by incoming information. In imagery, there can be an

[2] Essential methods are named: EEG, ERP, ERS/ERD, DC-EEG, MEG, PET, SPECT,CT, MRI, fMRI, TMS, rTMS and DOT (sometimes called OI or EROS). See Gazzaniga et al. (1998) for a brief introduction to computerized tomography (CT), magnetic resonance imaging (MRI), encephalography techniques (EEG derivates and MEG) and positron emission tomography

external cue for recall or creation of an image, but the experience is based on previously stored representation. This is clarified in the following assumptions:

> a) an auditory image involves a conscious experience
> b) this resembles in a certain, as yet unspecified ways the experience of hearing the sound in question directly, but
> c) the image can be present in the absence of any auditory signal, and
> d) it can be evoked intentionally by the subject
> Baddeley & Logie (1992:179)

Definition of imagery sometimes involves the term inner (or mind's) ear, which can be considered identical to Baddeley's working memory model's phonological store (see Smith et al. 1992). Musical performance, at the professional level, is an example of a very complex cognitive skill. Instrumentalists are able to play *prima vista* (perform motor preparation and actions), without previous memory of the piece, reading the score (perceive), interpreting it and receiving auditory feedback simultaneously (Sloboda 1985). To achieve this, human information processing must have organized very effectively and this organization is most likely described best as a system of representations and computations. This review will concentrate on imagery, but will introduce some perception and performance related results, as comparison.

Imagery is not a single phenomenon, but a collection of different types of situations. First, imagery can be triggered in two ways: voluntarily and involuntarily (Leach 2003). Voluntary recall is the type used in psychological experiments. In voluntary recall, I propose a distinction between two subtypes: full recall and instrumental (partial) recall (adapted from Pylyshyn 1981). These two types are differentiated by the amount of information needed to complete the task. The full recall requires the musical memory to be probed note by a note for some part of a song (e.g. in Weber & Brown 1986). Functional recall, on the other hand requires only partial information from a bigger representational unit (e.g. in Halpern 1988), e.g. imagining your mother's hair color compared to full recall of your mother's typical visual appearance.

(PET). Kosslyn et al (2001) has described SPECT, TMS and DOT in a compact fashion in his very review and Zatorre (1999) has good review to the PET methodology.

The involuntary recall of musical memories happens without the conscious effort. In the involuntarily recall cases we make a division into three: musical hallucinations in psychiatric and non-psychiatric individuals, and cognitive itch (song-stuck-in-your-head syndrome). All cases have been separately examined in literature, although the classes have not been grouped earlier.

Table 1. Different types of events triggering musical imagery

Recall type	Subtypes (example study)
1. Voluntary	
	a) Full recall (Weber & Brown 1986; Repp 1999, 2001)
	b) Functional (partial) recall (Halpern 1988)
2. Involuntary	
	a) Musical hallucinations, non-psychiatric (Berrios 1990)
	b) Musical hallucinations, psychiatric (Hermesh et al. 2004)
	c) Cognitive itch (Kellaris 2001, 2003)

In every imagery situation, the experience relies on a mental representation. Imaging unheard (new) music does not make a difference. Even though some authors (Sessions 1970 in Weber & Brown 1986; Leach 2003) emphasize the role of imagined new music as a composer's invaluable aid (pragmatic value) and Beethoven for one has made several compositions after acquiring deafness (Deutsch & Pierce 1992), the subject has been neglected in psychology. It won't be further speculated here, only to mention that there has been a related debate on the permanence of human memories. It has been shown that all memories are prone to change over time (Loftus & Loftus 1980), and so it can be concluded that new imagined music may not be unexpected incident but a natural outcome of the way our brain processes information.

The final challenge in exploring the musical experience is the nature of music. We already encountered a problem in defining music and bypassed it with selection criteria. It still doesn't change the fact, that music for humans is not only temporal organization of sound, but can also appear as singing, clapping or dancing. The musical experiences, and the representations, are crossmodal in nature. This means that together with an auditory image of a song (lyrics and melody), we may nearly always evoke a visual image or imagine the motor and visual performance on our own instrument (Petsche et al. 1996). And even if consider only the auditory properties of music, we've still got plenty to choose from, as people can identify music from rhythm or contour alone (Platel et al. 1997). Altogether this promotes the idea, that we have, at least in theory, many prototypes for musical experiences, not a single mould.

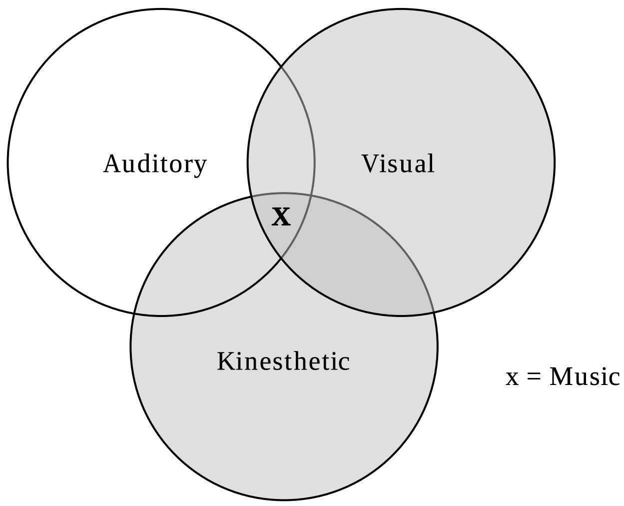


Figure 2. Music's crossmodal nature. Music is located in the intersection of auditory, visual and kinesthetic modalities.

2

Musical imagery in psychology

2.1 Basic paradigm in behavioral studies

The cognitive revolution started out with the realization of the internal previously neglected by behaviorists, giving rise to mentalistic psychology (Pylyshyn 1981; review in Kosslyn et al. 2001). Pioneer of the imagery research has been Steven Kosslyn who began the study of perception and imagery experiences' properties in the '70s. He believed imagery to be profoundly similar to perception, to share the same representation format. To prove his point, Kosslyn employed the methods of cognitive psychology and investigated visual imagery's spatial properties with a technique called scanning. It required subjects to respond supposedly based on perception like visual imagery. As a result he could show that there were similar properties, a functional equivalence between imagery and perception (review in Farah 1988). So it was natural that there would soon be auditory imagery studies as well, which share the background theories originally describing visual imagery in behavioral studies

Five models concerning perception-imagery -relationship exist. They can be applied to imagery-performance –comparison with some precaution. Functional models posit that imagery retains central properties and relations of perception. It doesn't correspond to perception in one-to-one proportion (so called second order isomorphism). Respect to functional theories, structural approach assumes stronger relation (first order isomorphism). It states, that there are many exact correspondences between these two cognitive functions. These two models can be tested with behavioral indices to some extent, revealing functional or structural equivalence of processes. Interactive models go even further, proposing that in addition to cognitive structure resemblance, two processes are not separate, but possibly interact within a single process and share a neural basis. This claim can't easily be justified on behavioral results, instead requires neuroscientific evidence that is now available (Finke 1985)

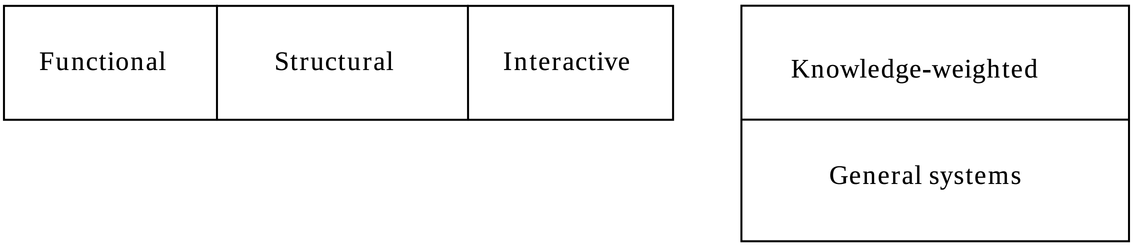


Figure 3. Models describing the perception-imagery –relationship.

Two models by Intons-Peterson et al. (1992) take a different perspective. First, the knowledge-weighted model takes advantage of many common concepts found in cognitive psychology. It proposes a format, modality specific canonical forms, for memory representations and supports similarity between perception and imagery. Last suggestion is the general systems model. It assumes imagery, perception and cognition to be at least partially indivisible and that imagery may, depending on circumstances, rely more on cognition (tacit knowledge) than on perception. It can explain the use of different strategies in imagery experiments. Both models by Intons-Peterson can be tested with behavioral experiments.

The musical imagery research has never been a big program, still some distinct methods exist. The first was adapted from Kosslyn's to the investigation of auditory imagery by Halpern (Halpern 1988). She addressed the properties of imagery by asking subjects to judge the pitch difference between two points in a familiar song, cued by a pair of lyrics. Successful recollection requires information from two parts of the musical representation, so strictly speaking it must be considered as a functional recall, although it is assumed that subject runs through the whole piece. If subjects can answer at above the chance level, it indicates that they represent the song, in a way reserving the pitch related information. As a result, she observed a very low error rate (5-6% depending on the setup) and an increase in reaction times as the function of distance (measured in beats) between presented lyrics. This musical scanning method and its variations have thereafter been used in several studies e.g. Zatorre et al. 1996, Aleman et al. 2000.

The other prominent method has been the imagery generation and rehearsal of music. It started with experiments requiring imagery of simple musical elements, like tones, chords and tempos (reviewed in Hubbard & Stoeckig 1988 and Halpern 1992). These experiments did provide some information on the characteristics of auditory imagery, but can't be accounted here as music investigations. Weber and Brown (1986) tested the interactive model of imagery. Their method included the memorization of unfamiliar music and the overt (sang or hummed) or covert performance (transformed to contour visualization on paper). This differs from musical scanning in a way, that successful performance requires quantitatively more information about the song, demanding full representation of the pitch pattern (full recall). Their results, matching processing times and errors indicated shared processes (functional equivalence) for imagery and performance. Very similar procedures without references to Weber and Brown have been applied by other authors (Repp 1999, 2001).

2.2 Neuropsychology

There were not many behavioral methods for studying imagery in healthy subjects. But the existing ones can be used more effectively if we can add new variables to the experimental setup, in particular brain damage. Neuropsychology allows inferences about neuroanatomic parallelism of perception, imagery and performance processes and identification of critical areas for music (for review, see Zatorre 1999). The most informative deficit concerning imagery research is the amusia (music agnosia), a selective loss of musical abilities preserving other auditory capabilities. Since the late 19th century, acquired and congenital amusia have been described in literature in almost two hundred cases (Platel 2002, review in Vignolo 2003). Still exact diagnoses of patients' musical deficits have not been possible until the behavioral indices developed to the modern standard (Ayotte et al. 2002).

Acquired amusia is a bit more thoroughly understood defect. Some recent example s include almost total musical amnesia in a non-musician (Peretz 1996) and expressive amusia with specific problems in pitch and rhythm processing in a professional (discontinued occupation) musician. Variability in cases suggests that amusia can be divided into receptive (auditory), expressive(motor), and mixed (both) types (McChesney-Atkins et al. 2003). Vignolo (2003) made a review to cases in the literature, which could not suggest a clear conclusion due to divergence in case reports. Therefore he devised an experimental study, which magnified the possible dissociation between music and environmental sounds and supported previous reports of specific melodic or temporal deficits in music.

Unfortunately there are very few systematic neuropsychological studies addressing musical imagery. A group of lobectomy patients with mild musical disabilities (dysmusia) where examined in a study focusing on perceptive and imaging abilities (Zatorre & Halpern 1993). Musical scanning was used as an imagery task and the perceptual task was a modified version of the same. The central finding was that right temporal lobectomy equally impaired the performance in perception and imagination whereas patients with left temporal-lobe excisions where not defected. “These results support the idea that imagery arises from activation of neural substrate shared with perceptual mechanisms, and provides evidence for a right temporal-lobe specialization” . Due to the large area of a neurologically removed tissue, no finer localization was possible. Based on this evidence, it seems that receptive amusia will result in imagery amusia also.

2.3 Cognitive neuroscience

After the new methods for acquiring information about the brain came available, visual imagery research adapted them (PET, TMS) quickly. Neuroscientific experiments, still based on the behavioral experiments, could provide considerable more quantitative information, less problems with experimenter expectancies, and some sort of a possibility to control subject’s mental functions (Kosslyn et al. 2001). The first investigation into neural basis of music perception was done as early as 1982 (Mazziotta et al. 1982 in Platel et al. 1997). Thereafter the program has expanded, although the emphasis has been on the music perception and execution, not imagery. For this review I found nine publications dealing with musical imagery, directly or indirectly[3]. Most investigations seem to be motivated by the interactive model assumption, even though the authors don’t usually announce the testing of any particular model.

[3] Van Lare, JE, Zielinski & Rauschecker (1999) Anticipatory musical imagery: functional MRI studies of the human brain. In *Intl. Soc. For Sys. And Comparative Musicol.* Norway: Oslo was unavailable for review.

Table 2. Music related Imagery studies in cognitive neuroscience by 2004.

Author	Year	Subjects (a/b/c)	Imaging method	Setup (x/y/z)	Recall type
Musical imagery studies					
Beisteiner et al.	1994	?/-/-	EEG	x/-/-	L
Petsche et al.	1996	1/-/-	EEG	x/x/-	L
Zatorre & Halpern	1996	-/12/-	PET	x/-/-	N
Halpern & Zatorre	1999	8/-/-	PET	x/-/-	L
Langheim et al.	2001	6/–/-	fMRI	x/o/-	L
Ohnishi et al.	2001	14/-/-	fMRI	x/x/-	L
Ducreux et al.	2003	-/-/9	fMRI	-/-/x	N
Kristeva et al.	2003	7/0/-	EEG	–/x/-	L
Lotze et al.	2003	8/8/-	fMRI	-/x/-	L
Pascual-Leone et al.	unpubl.*	9/-/-	TMS	-/-/x	N
Auditory, non-verbal imagery studies					
Hoshiyama et al.	2001	–/7/-	MEG	x/-	L
Schürmann et al.	2002	11/0/-	MEG	x/–	N

* reported in Halpern (2001).
Subjects: a is the number of musically trained subjects, b is the number of musically non-trained subjects, c is the number of subjects whose musical skill has not been specified.
Setup: x is perception vs. imagery comparison, y is imaged vs real performance comparison, z is imaged music without

As seen in the table, a division to three can be made to classify the studies. Some authors investigate the perception-imagery –relation, some concentrate on comparing imagery and performance, and there others who wish to address imagery in isolation. To makes things a bit more complicated, there are studies combining the two former cases. We'll inspect the perception vs. imagery studies first.

The first auditory imagery study used DC-EEG to investigate activation related to different mental tasks of music processing. The obtained results were not significant, but showed a trend towards right hemisphere dominance in music perception condition that shifted to the left hemisphere during imagery (Beisteiner et al. 1994). A bit more advanced experiment employed the PET technique (Zatorre et al. 1996). This study was motivated by previous findings in neuropsychology (Zatorre & Halpern 1993) and actually replicated the previous experiment using functional imaging. Investigators found out that imagery and perception indeed activate many common areas, excluding the primary auditory cortex. In contrast with the neuropsychological study, the activation was bilateral, suggesting the involvement of the left temporal cortex. Based on these findings authors suggested that although they was activation, it might be epiphenomal (unnecessary side-effect). They also hypothesized that the left activation might indicate more language processing (phonetic information) and the right activation more task-critical pitch discrimination. As bilateral activation did not fit in well with previous results, the researchers modified their setup to better bring up the aspects of musical experience. In a new experiment, they concentrated on instrumental music material rehearsal in contrast with previous excerpts that contained also lyrics (Halpern & Zatorre 1999). Musically trained subjects where scanned with PET. The results confirmed with the previous studies, showing significant activation in right superior and frontal temporal lobe, supplementary motor area (SMA) and right inferior frontal area.

TMS is not an imaging method like PET. Instead it can be used to inhibit brain activity and create simulated transient lesions. It requires that the becoming lesion area is locate on the cortex surface, which is a bit of problem in auditory area stimulation as secondary auditory cortex, the locus of interest, is not available for direct stimulation. When TMS was applied to the right auditory cortex during an experiment that required subjects to make pitch judgments, it significantly increased the reaction times to instrumental stimuli. The effect was not significant for verbal tunes and for the stimulation of left auditory cortex or SMA. The missing SMA effect made the authors to suggest that either the stimulation was inadequate or that the SMA activation, as observed in the previous experiments, was not necessary for completing this task (Pascual-Leone et al. in Halpern 2001).

Investigation made by Ducreux et al. (2003) also compared perception to imagery. They claimed to have shown activation the primary and secondary auditory area bilaterally, but the significance of their findings and possible causes for their deviant results can not be considered here in detail, as their publication was not available while making this review.

Another set of publications has explicitly examined the mental rehearsal of music, a technique known to be used by professional musicians (Kristeva et al. 2003; Rauschecker 2003). First subgroup of studies compares perception to imaged execution, the second covert performance to overt performance. As an example of the former, Langheim et al. (2002) studied skilled musicians of various instruments. Their setup required subjects to mentally play a very familiar composition. Using fMRI they found increased metabolic activity during imagined music in premotor- and supplementary motor areas, right superior parietal lobule, right inferior frontal gyrus, bilateral mid-frontal gyri, and bilateral lateral cerebellum. There were activation neither in the primary or secondary auditory cortex nor in the primary motor area. The results indicate "an associative network independent of primary sensimotor and auditory activity ... cortical elements most intimately linked to music production". Imagined musical performance (IMP) was also investigated by Ohnishi et al. (2001) They compared perception of an instrumental piece to mental performance of a different composition, carried out by professional musicians. Their fMRI imaging revealed similar activity for both conditions in the auditory association cortex, especially the posterior superior temporal gyrus. This finding resembles the perception vs. imagery findings to a great extent.

The most recent publications address the question of similarity between real and mental performance. Professional and amateur violinists were compared in an fMRI study requiring subjects to play an extract of a familiar concerto (Lotze et al. 2003). Their setup required left hand movement on an artificial instrument, omitting right hand. As a result, both conditions induced similar activations in multiple areas, especially motor excluding the primary motor area. They also showed a significant effect between groups, especially in the imagery condition displaying fewer activated cerebral areas for professionals, which was interpreted as a more efficient recruitment of acquired knowledge. They didn't observe activation in auditory areas, which might be a result from motor emphasis although the subjects reported vivid imagery for sounds also. A similar study was performed with EEG, also comparing overt performance with a real instrument (violin or viola) to covert performance (Kristeva et al. 2003). The results showed correlation between imagery and performance in several locations, measured in music processing and preceding negativity potentials.

Coherence analysis for EEG was used in another study, involving perception, imaged performance and real performance. One professional violinist produced distinguishable coherence changes for electrode (Fz) placed above SMA which where successfully duplicated after a 5 days interval. Results showed that playing involved most the Fz, imagery less and perception even less. (Petsche et al. 1996)

There are two related non-musical studies, both carried out with MEG, addressing non-verbal auditory imagery. The first study involved the imagination of an environmental sound, a hammer on anvil (Hoshiyama et al. 2001). In the imagery condition six of seven subjects showed consistent activation around the inferior frontal and insular areas, dominantly in the right hemisphere. The second study required the participants to imagine a tone corresponding to a visually presented staff mark (Schürmann et al. 2002). Comparison of imagery and control conditions revealed activity specific to imagery in occipital and extraoccipital areas, and finally in sensorimotor cortex. One ECD was located also on the left anterior superior temporal sulcu, the auditory association area. Results from the former study appear quite compatible to other auditory non-verbal imagery studies but the latter research revealed a set of activations not previously emphasized. Difference in the tasks and techniques makes it hard to evaluate the significance of these findings, even between these two approaches, as a different approach to dipole modeling was used and results.

2.4 Methodological criticism

There are some difficulties in studying mental behavior with behavioral indices. There are three influential arguments that question the inferences made based on these results. The most profound criticism towards imagery was presented by Pylyshyn (1981), who argued that findings of imagery experiments could be fully or partially explained in terms of general-purpose cognitive processes, using tacit knowledge. He therefore suggested that the experienced similarity to perception could be dysfunctional (epiphenomal) and experiments could be instead solved applying a tacit propositional knowledge. This would lead to observed functional equivalence. When behavioral methods where primarily used, tacit knowledge was still a very competent claim, but after the invasion of imaging studies,, it has lost some of its charm. Next quote tells why.

> A tacit knowledge account of the ... data... would need to include the following two assumptions:
> a) that subjects know [tacitly] what parts of their brains are normally active during vision and
> b) that subjects can voluntarily alter their brain electrical activity, or modulate or increase regional blood flow to specific areas.

Although the argument is strong, it must not be interpreted to indicate the insignificance of cognition or propositional knowledge, only the possibilities of analogue format. As was mentioned (2.1) some models of imagery consider the tacit knowledge as well (Intons-Peterson et al. 1992).

The neuroscience has also abolished another argument against functional equivalence of imagery. The expectancy argument proposed that the obtained, equivalence confirming results in imagery studies may be due to extraexperimental influences, like the expectancies of the experimenter and the subject, and the demands in the current setup (described in Farah 1988; Zatorre et al. 1996). This doubt rose from the difficulty to duplicate some of the earliest visual imagery findings in behavioral studies. The problem still exists in neuroscience, but the emphasis has shifted from data acquisition to interpretation (Kosslyn et al. 2001).

Last argument considers the modality specificity of representations. After the first visual imagery experiments it was shown by several research groups that some tasks supposedly requiring analogue visual representations were successfully performed by congenitally blind. This suggested use of non-visual spatial representation and questioned the role visual representations in completing the presented tasks (described in Farah 1988). This argument also still holds some importance as it is possible to reach functional equivalence using different types of representations and use different strategies especially when imagery is not controlled. Farah (1988) states that problem can be bypassed if we arrange our experiments so that only one type of representation can be used, although it could be argued whether this is possible. In music, this is not the only problem with modality, related difficulties are described in the chapter 2.5.

In addition to these well-acknowledged arguments that affect all behavioral data, there are some difficulties that concern especially the cognitive neuroscience.

First is the measuring equipment, which plays essential role in the investigations. It has been noted that considerable differences in sensitivity exist between techniques and that alone can result in significant differences between experiments, not to speak of setups (Kosslyn et al. 2001). The difference was especially notable in visual imagery low-level activation, whereas specified high-level activation has been successfully detected with all techniques. For that reason Kosslyn et al. voiced their preference function, favoring fMRI more than PET and PET above SPECT for use in imagery studies. The visual and auditory domain are not well-comparable, their typical stimuli have totally different properties which probably reflects on their processing mechanisms, and auditory imagery relies on some specific domain specific functions. Nevertheless it must considered that the possible differences ay derive from the experiments' techniques, not only setups.

Finally, one aspect related to encephalographic techniques examining auditory perception is the possible involvement of anticipatory middle-ear muscle reflex. It's activity can generate artifacts to experiment data and should be controlled (Bench 1971 in Hoshiyama et al. 2001). Luckily this does not affect the majority of imagery studies as the used techniques probably circumvent the problem (see table 2).

2.5 Problems with expertise and attention

In visual imagery studies, the used stimuli and manipulations are usually equally familiar or unfamiliar to all subjects and there are usually no subgroups that could be considered more experienced. Subject used in the musical experiments are usually trained musicians, whereas regular people have received only minimal formal music education. It has been shown that musical training began early in life greatly shapes our brain. This may significant effect on observed results.

> When entering more advanced processing stages, including many neuropsychological laboratory experiments, the learning biography, determining the multiplicity of different auditory representations may influence the actual network used for music processing ... processing strategies may lead to a simplified or to a more complex way to listen to the stimuli or music.
> Altenmüller (2001) 278

Neuroplastic changes can be extensive, at various levels of neural organization (Schlaug, 2003) and the effects of musical training are attainable fast, as shown by Bangert & Altenmüller (2003). Altogether musical training leads at minimum to augmented sensimotor representations and new cortical connections (Pascual-Leone 2003).The current numbers in imagery research (table XXX) speak strongly in behalf of expert's brain research, which must be acknowledged when evaluating results. In general, it should be required from all studies that participants' musical education is well controlled and reported, otherwise systematic errors will rise and the research can't be compared to others at all, which is currently a real problem.

Musical imagery can require complex skills, as do perception and performance. The use of skilled musicians may be justified in experiments that solve questions about group differences or high-level musical performance, as the majority of reviewed studies have done. But especially with skilled musicians, we encounter another problem. That is the nature of musical experience, multi-component structure and crossmodality of music (see chapter 1.1, figure 1 and 1.3, figure 2) contrasted to attention. Musicians usually realize the crossmodality aspect themselves, in experiments requiring only motor performance, musicians find it impossible not to imagine the sounds also (Petsche et al. 1996; Lotze et al. 2003). Many cognitive psychologists, at least in the past have discussed this issue in their publications. Weber and Brown (1986) mention the crossmodality and present their ways to deal with the problem, manage to be quite plausibly.

It was shown that musical representations can have a very complex structure so we need to consider the effect attention can possible have on musical experience. Attention influences brain responses (Näätänen 1992), so we must think about the possibility that almost identical instructions in an experiment could lead to considerable different brain activation patterns, as has been demonstrated for perceptual task (Platel et al 1997). In musical imagery, this could mean that concentrating more on rhythm instead of contour would greatly shape the results. Fortunately the bias in individual subjects (e.g. a wrong interpretation of instruction) is usually avoidable if we compare several subjects, but a systematic bias can result from experimental flaws. Another aspect of task related attention was already mentioned (ch. 1.3), when discussing full and instrumental type of experiments, that may require totally different cognitive functions and types of information (see Farah 1988). In trials that imitate performance, there is also a great chance that the brain activation reflects only motor components, which can be specific to the subject or the instrument. This trap can be partially dodged, as Langheim et al. (2002) did, using averaging over different instrument players to bypass the possibility for shared motor programs.

2.6 Summary

> Mental imagery has, until recently fallen within the purview of philosophy and cognitive psychology. Both enterprises have raised important questions about imagery, but have not made substantial progress in answering them.
> ---
> To the extent that the same conclusions are reached using different methods, the conclusions drawn from these studies can be taken increasingly seriously. (Kosslyn et al. 2001:635)

The imagery research had started mimicking visual imagery studies, although it was soon realized, that auditory imagery had some distinct features, especially the use of subvocalization (inner speech, mental rehearsal in working memory; Smith, Reisberg, & Wilson, 1992) that justified the creation of auditory specific procedures. Before the advanced technology of modern cognitive neuroscience became available, there was already evidence for the interaction model of perception and imagery. Behavioral studies issuing musical imagery (e.g. Weber & Brown 1986; Halpern 1988; Hubbard & Stoeckig 1988) had demonstrated functional equivalence between these cognitive domains. Neuropsychological findings gave more reliability to the interaction model and suggested the lateralization of musical functions to the right temporal lobe (Zatorre & Halpern 1993). The lack of an amusia that would selectively impair musical imagery also implied that these functions would be intimately coupled.

The studies in cognitive neuroscience show that imaged perception or execution seems to evoke activation patterns very much like real stimulus or motor action, albeit the details vary greatly from study to study. This is a clear evidence for neuroanatomical parallelism (Zatorre 1999), a shared neural substrate of perception and imagery. The critical cortical areas for musical perception are auditory (A1, A2) for imagery, the auditory association cortex (A2) seems to be more crucial and imagery might do without the primary area (A1). This makes a significant difference between auditory and visual domains, as visual imagery seems to active the primary sensory areas (Kosslyn et al. 2001).What the A2 area really does is uncertain. Halpern & Zatorre (1999) speculate that "[higher-order processes in A2] might include the internal representation of complex familiar stimuli" and that's about the only guess there is.

Imagined performance proved also to have similar neural correlates with real (or close to real) musical performance, so it fits the interactive model (originally proposed for perception-imagery –relation). There are no remarkable cognitive theories about imagery performance in psychology (see Weber & Brown, 1986). The lack of theories is quite interesting when we consider that the role of mental rehearsal has been well-acknowledged among professional musicians (Kristeva et al. 2003; Rauschecker 2003). The findings that show alike neuroplasticity as a result of mental and real training (Pascual-Leone et al., 2003) have confirmed this intuition. Concerning musical imagery it must mentioned that the effect was observed on motor cortex. Altogether this emphasizes that imagery and corresponding overt musical behavior share at least partially a common neural substrate.

Localization of cognitive functions is essential in the search for neural substrates. The common opinion has suggested "language on the left, music on the right" view, acknowledging that lateralization might be affected by musical training. (Altenmüller 2001). Based on imagery studies, the dominance of the right hemisphere seems indisputable, even in skilled musicians (Halpern & Zatorre 1999). In terms of cognitive structure, it seems that the experience in perception and imagery derives from activity of many shared modules, without a particular imagery unit. As was noted earlier, music perception can plausibly be dissociated from speech and environmental sound recognition. Components of music might also be realized in their own modules, localized to different hemispheres. Cytoarchitectonic differences,depth- electrode recordings, and neuropsychological findings have lead to a proposition that temporal properties (tempo and meter) are processed in left and spectral (contour, harmony) in the right hemisphere (Zatorre et al. 2002; Vignolo 2003).The question about how separate these components within musical and auditory domains really are is a tough one. There are results from behavioral experiments (Aleman et al. 2000) showing that musical training enhances the imagery ability in the whole auditory domain, not only in musical functions and demonstrating the modality specificity of imagery as groups scored equally in visual imagery tasks[4]. There were no significant differences in a perceptual task. These findings promote the possibility that even if there are separate modules within auditory system, there are also common structures which greatly affect the function of the whole.

[SMA and subvocal]
The studies have revealed some oddities also. More complicated investigation has given a lot of data but plausible interpretations are hard to come by. One detail from the perception-imagery –comparison was the unexpected motor activation (Zatorre et al. 1996, Halpern & Zatorre 1999). The role of this finding has remained mysterious (Halpern 2003), but it has been suggested that subvocalization, which has a functional role in musical imagery (Smith et al. 1992), could cause the observed effect.

3

[4] Although the particular results could derive from an innate differences between groups

Musical hallucinations

3.1 Introduction

Musical hallucinations (MHs) are a rare and poorly understood phenomenon (Berrios 1990). The ongoing confusion about the essence of musical experiences shows in the contemporary literature as the similar symptoms go under a variety of names. In the reviewed publications they were named as musical hallucinations, musical hallucinosis (organic hallucinations[5]), Charles Bonnett –syndrome (Brust 2001)[6], pseudo hallucinations[7], endomusia (Campbell 1996), release hallucinations[8] or reminiscence (Sacks 1998). They can be prefixed with hypnogogic to mark that the event is present only in the phase of falling asleep (David & Fernandez 2000). Despite the differences in word form, they refer to a same sort of experience. Hallucination can be defined as “an apparent perception of an external object when no such object is present” (Hinsie & Campbell 1970 in Boza 1999).The word itself comes from Latin expression alucinari, “to wonder in mind” (Boza 1999) and has been used in psychiatry since the beginning of 19th century (Sacks 1998).

Hallucinations are not a homogeneous phenomenon, but instead come in many forms and degrees of severity. They are not solely symptoms of some psychopathology, as they can also occur in otherwise healthy subjects in a transient or persistent manner. Therefore hallucinations are considered as both psychiatric (functional) and neurological (organic) phenomenon (Sacks 1998). This goes for MHs also. Organic causes are usually brain or ear damage whereas functional causes are psychopathologic disorders, which in the absence of any apparent physical damage to the brain cause the subject to hallucinate (Hermesh et al. 2003).

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[5] Organic hallucinations are “unrelated to psychotic hallucinations” (Berrios 1990).

[6] Charles Bonnet’s syndrome was coined in 1769 and is descbribed as “persistent recurrent visual hallucinatory phenomenon of pleasant nature, with a clear state of consciousness, compelling, but seen by patient as unreal” (Boza 1999).

[7] Pseudo hallucinations are defined as “occurring in inner space and being accompanied by insight” (Berrios & Dening 1996).

[8] Release refers to a release of previous memories, identifiable by the subject.

A finer grained classification has also been introduced. Berrios (1990) made a comprehensive review to MHs and classified four groups of typical causes: disease of the ear, neurological conditions, psychiatric pathology, and toxic states.

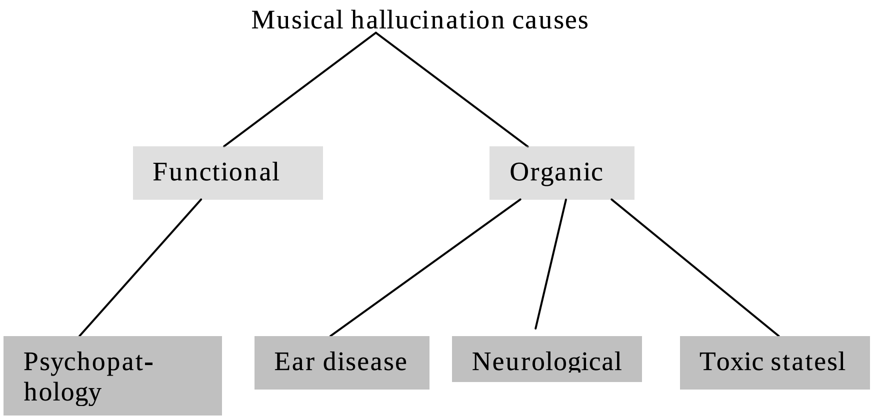

Figure 4. Division of musical hallucination causes as suggested by Berrios (1990) (dark grey boxes) and the standard model (light grey boxes).

Analysis can be taken even further. The three non-psychiatric classes can be shattered to five or six different categories (Boza 1999):

1. Hallucinations during psychological events (non-psychiatric conditions)
2. Use of psychotomimetics and prescribed medication
3. Neurological disorders
4. Medico-surgical conditions
5. Environmental and industrial causes
6. Pseudo hallucinations

3.2 Possible causes

In neurological and psychiatric publications, case reports usually include a hypothesis about the probable cause of hallucinations. A comprehensive list of non-psychiatric and psychiatric causes will be presented next. Thesix category classification (Boza 1999) will serve as a basis for classifying non-psychiatric causes, even though it is not a theoretically finished one and does not especially focus on auditory hallucinations. The first category hallucination is caused by a psychological event. Event’s definition includes stress, anxiety (both transient), sensory or sleep deprivation, acquired (peripheral) deafness and flashbacks (Boza 1999).

Next grouping considers drugs like LSD and prescribed and over the counter medications. The effects can be direct and indirect, appearing under influence of psychotomimetic substance or after prolonged periods of usage, like with alcohol. The third division is neurological aetiology. This means they are caused by abnormal electric activity in the brain, as sometimes in epilepsy or migraine. Electrical abnormality can also be caused by invasive neuroscience or physiological oddities, like grenade shrapnels encapsulated in soldier's brain tissue (Boza 1999). These hallucinations are usually labeled as release hallucinations.

Fourth class named as medico-surgical consists of hallucinations caused by progressive disease or a brain surgery. Examples include diabetes mellitus, multiple sclerosis and Charles Bonnet's syndrome (CBS) (Boza 1999). Organic hallucinations (hallucinosis) caused by a brain damag would probably also fall to this category (in ICD-10 1993), as would Lyme disease patients (Stricker & Winger 2003) and maybe the patient, who began to experience MHs after liver transplantation (Fukunishi et al. 1999). One brain stem lesions could be placed to this category as well (Murata et al. 1994).

The fifth category hallucination is caused by environmental aetiologies. Cases like transient tinnitus and mirages belong to this category (Boza 1999). Hallucinations experienced by extreme altitude climbers due to lack of oxygen should be included in this category (Brugger et al. 1999), although not originally mentioned. This category seems poorly constructed as it seems to be a some sort of a subclass of the first category, psychological events.

The last class is called pseudo hallucinations. They break the hallucination pattern in a way that the subject is aware that there is no external source for her false perception. Example cases include radio-reception from shrapnel piece and hallucinations evoked by virtual reality experience (Boza 1999). Pseudo hallucinations can also take place in non-psychiatric subjects without any obvious reason. This sixth category seems ambiguous, as some earlier classes could be included in this category as well and there clear cause for the hallucinations is presented.

Finally, hallucinations may be caused by a mental illness. Schizophrenia is probably the best known example of a psychopathology in which patients often (70%) experience dominantly auditory hallucinations (Sartorius, Shapiro, & Jablensky 1974 in Lobban et al. 2002; Smith 1992). In schizophrenia, MHs are generally considered as pseudo hallucinations, originating from musical memories, whereas the verbal hallucinations are more likely to be classified as "real" hallucinations (Baba et al. 2003). There are also many other disorders that include hallucinations among their symptoms, but only the obsessive-compulsive disorder (OCD) and depression are mentioned as they are sometimes associated with auditory and occasionally MHs (Zungy-Dirwayi et al. 1999). It was recently shown, that MHs are most common in inpatients with OCD, compared to other disorders, including schizophrenia and the major depressive disorder (Hermesh et al. 2004). MHs can alone be adequate symptom for an OCD diagnosis, in which case hallucinations are called musical obsessions or endomusia(Zungy- Dirwayi et al. 1999). Depression has been mentioned in some case reports as a contributing factor for but there are no systematic studies about it's relation to MH and so the causal connection is uncertain (Fenelon, Marie, & Ferroir 1993 in Hermesh et al. 2004; Fukunishi et al. 1999; Zungu-Dirwayi et al.1999; Iijima et al. 2000).

3.3 Case examples

Hallucination research like neuropsychology relies heavily on individual cases and theories are built on that data, not so much on systematic experimental investigations. Examining cases with organic causes can also be useful to cognitive scientist because the findings should be compatible with an adequate model of a cognitive architecture, based on the notion of breakdown pattern in modular information processing systems (Fodor, 1983)[9]. As the possible causes were introduced, the phenomenon will be further elaborated in case examples. For additional information, I suggest the comprehensive review by Berrios (1990).

Peripheral or cortical deafness is possibly the most common organic cause. Griffiths (2000) reports six cases in his study. They all had moderate (or severe)

[9] This is comparable to destroying a tire or the reverse gear from a working car. Both affect the functionality, but in different ways.

acquired deafness with MHs. The patients, aged between 58 and 82, had a continuous experience of perceiving music without external stimulus. The hallucinated music was usually familiar to patients, although only two subjects, with less severe deafness, heard contemporary music. Songs were usually accompanied with a singer or a choir, one or several instruments and four of the six patients perceived the lyrics (generally). None of the patients got relieve from a hearing aid and they did not receive medication.

A similar case was investigated by Izumi et al. (2002) whose patient was 51-year-old man experiencing musical and verbal hallucinations. He sought help because the verbal hallucinations distracted his job, even though he had an insight that he was indeed hallucinating. MHs were described as entertaining popular songs with melody and lyrics. He had a considerable hearing loss but no other symptoms. This and Griffiths' patients found their condition distressing and had requested treatment, so their experiences would not speak for auditory corresponded of Charles Bonnet's –syndrome (CBS) as hallucinations in CBS are usually considered entertaining and harmless.

Lesions in subcortical structures that do not result in a hearing loss may still cause MHs. Cerrato et al. (2001) examined a patient, 35-year-old-male with a left subcortical haemorrhage, who had experienced musical pseudo hallucinations for a short period of time accompanied with right hand clumsiness. His hallucinations did not reoccur and he did not have history of psychiatric disorders. Alike case was examined by Schielke et al. (2000), who described a 57-year-old-man with a dorsal pontine lesion. He experience left-sided tinnitus, right-sided MHs (boy choir singing folk songs) without other psychopathologic symptoms and had some motor problems. During five weeks of hospitalization hallucinations resolved. Authors reviewed ten similar dorsal pontine lesion cases, in which six patients finally got rid of the hallucinations without medication.

Medication can cause pseudo hallucinations, as in a patient described by Hambrecht (1995). His patient experienced both visual and auditory (not music) pseudo hallucinations as a side effect of lithium. Hallucinations subsided when medication was discontinued. MHs also occured in another patient as result of a too big antidepressant dosage (Terao 1995). The patient, 40-year-old-man, witnessed hallucinations occurring in silent environments after a week from change in his medication. He claimed to have heard 'supporting songs in his right ear and nursery rhymes in his left ear', including the song "Mickey Mouse". He did neither have a hearing loss nor structural abnormalities (CT scan), so this case is not comparable to Griffith's patients.

MHs sometimes respond to medication in a positive way. David & Fernandez (2000) successfully treated an old woman suffering from hypnogogic musical (release) hallucinations. Her hallucinations were real, as she believed that her neighbor was holding parties when she tried to fall asleep. She also suffered from progressive deafness, like Griffith's patients. She was treated with atypical antipsychotic queatiapine which afforded her near total resolution of hallucinations without adverse effects'. Positive results were also acquired by Izumi et al. (2002) who applied mixed medication (sulpiride, risperidone and anticonvulsant valproate) offering improvement to musical and verbal hallucinations. These findings along with known effects of LSD (Boza 1999) illuminate the capacity of psychoactive ingredients to influence the implementation level of cognition, synaptic connections. Unfortunately this evidence doesn't allow many inferences about our cognitive architecture, maybe excluding the synesthesia produced by LSD. Also when considering hallucinations as side-effects, it must be remembered that these are very rare literature and medication doesn't provide hallucinatory side-effects to the majority of users.

3.4 Brain imaging

Modern psychiatry takes advantage of the same brain imaging techniques as cognitive neuroscience. It is clear that the use of these methods is somewhat more difficult, as the research target, hallucination, is more unstable than most normal cognitive processes are (Egan et al. 2000). In spite of the challenge, several investigators claim to have spotted the neural correlates of hallucinations, including MHs. Griffiths (2000) carried out a PET imaging for six hallucinating subjects. He found clusters of correlated activity in the posterior temporal lobes, the right basal ganglia, the cerebellum and the inferior frontal cortices. Activation was positively correlated with subject's verbal reports of their hallucination's severity. They was no activation in the primary auditory cortex.

Kasai et al. (1999) examined an 88-year-old-female patient with SPECT imaging and found right-sided temporal activation, especially in the auditory association cortex, during the MHs. Right side differences were also observed with MEG. Another similar SPECT study found activation in the bilateral lower frontal area and the bilateral basal ganglia (Izumi et al. 2002). There were neither significant differences between hemispheres nor activation in temporal lobe region. Authors of that study reviewed previous studies imaging studies, including Griffiths (2000), Kasai et al.(1999), and Erkwoh et al.(1993)[10], which have all demonstrated temporal lobe activation, making this study an exception. The authors suggested that this anomaly might be a result of patient's continuous tinnitus (present in the baseline condition) and the used subtraction technique, which could diminish all small changes in auditory cortex activation.

Last study is not strictly speaking an imaging research, but describes the release hallucination phenomena from a neurological perspective. This very famous group of cases was introduced by neurosurgeons Wilder Penfield and Phanor Perot (Penfield & Perot 1963).During the previous 25 years Penfield had developed a neurological procedure for identifying the locus of epileptic activity. While his patients were prepared for the surgery, he used electrical brain stimulation, simulated seizures, to explore the cognitive functions of the cortex, e.g. discovering the motor and somatosensory homonculi (Gazzaniga et al. 1998; Tees 1999). In some patients the stimulation of temporal lobes elicited vivid memories of different kind in an unpredictable way. Memories could be almost anything from undistinguishable sounds and visions to discrete situations from person's life. In a group of 40 patients, auditory responses uniquely were encountered 66 times, compared to 38 times for visual responses and voices (46) were more common than music (17). Findings were interesting as it was previously known that systematic hallucinations, also music, could sometimes precede or trigger epileptic seizures. As the stimulation was supposed to simulate seizures in a crude way, results suggested that the systematic hallucinations might be generated in the locus of epileptic seizure (Penfield & Perot 1963).

[10] Erkwoh R, Ebel H et al. (1993) *Nuklear medizin* 32, 159-163. Unavailable for review.

EEG has a restricted spatial resolution and it has been this far neglected as imaging technique in this work. There are a few reported EEG recordings during MHs, which generally reported right hemisphere focus of activation (Berrios 1990). Sacks also recorded increased bilateral temporal activity from his neurological patients (Sacks 1998). These results are in line with the other findings, although Sacks coined his findings as musical epilepsy, comparable to experiential hallucinations depicted by Penfield.

3.5 Theories

There are three traditional hypotheses to account for schizophrenic hallucinations. The continuity (or continuum) hypothesis makes an assumption that all mental experiences are arrayed along some common axis and so there is no fundamental difference between regular perception, hallucinations, and imagery experience. This hypothesis is a sensory-receptive explanation of hallucination, although it doesn’t describe how hallucinations are actually generated. Imagery theories of hallucinations state that hallucinations are intimately related to imagery, either to impoverished or peculiarly vivid one. Neither of these hypotheses has found consistent support. It’s noteworthy that imagery has a slightly different, more sensory connotation in psychiatric than in psychology. Finally, there is subvocalization theory which attributes schizophrenic voices to false interpretation of self-generated inner speech. This view has some supporting evidence from empirical studies (Smith 1992).

There is also a cognitive explanation for schizophrenia’s hallucinatory experiences, the imbalance hypothesis (Vogeley 1999). It relies on the imagery and subvocalization hypotheses but adds certain cognitive elements to the explanation. “It has been argued that the development of hallucinations is due to a self-monitoring disturbance”. This means, that the information processing system can no longer distinguish between internally generated images and images created by external stimuli. This reality monitoring is normally achieved by metacognitive skills which seem to be dysfunctional in schizophrenics (Lobban 2000).

The two neurally motivated hypotheses about schizophrenia exist as well. Dysconnectivity hypothesis is a general account for schizophrenia, stating that prefrontal cortex and posterior brain regions disconnection leads to hallucinations. Hyperassociative theories assume the opposite, increased connections between cortical areas (Vogeley 1999). In line with the latter, it has been suggested that MHs result from "a hyperactive state of the peripheral auditory system and that they develop out of rhythmic tinnitus" (Gordon 1997 in Hermesh et al.2004). This theory has been often referenced in literature but not evaluated seriously. It still has some plausibility as many patients with musical pseudo hallucinations also suffer from tinnitus and people with tinnitus experience MHs (Johns et al. 2000). One hypothesis speculates about the brain stem lesions causal effect on hallucinations (Schielke et al. 2000). It states:

> Acoustic stimuli might be distorted to auditory illusions if these [auditory] pathways are interrupted. Accordingly, physiological sounds like the noise of pulsating arteries could be perceived as tinnitus or other illusory sounds. (Schielke et al. 2000:454-455)

Considering the evidence, both hypotheses make only an educated guess. Griffiths does more than that. He has proposed a cognitive neuropsychological "model for the normal and abnormal perception of patterned-segmented sound" called trigger model. It consists of modular mechanisms with separated functions. It is visualized in the following model

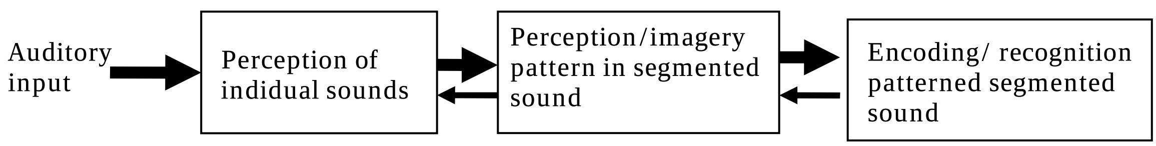

Figure 5. Model for musical processing. Adapted from Griffiths (2000). Feedback from segmented perception module to individual sound module has been added as described in article.

The idea of the model is that if we considerably impair the auditory input, the perception modules don't just die off, but continue to generate spontaneous activity. This activity provides a weak input to recognition module, which in return generates strong positive feedback to segmented recognition module and "lead to misperception and misrecognition of certain incoming sounds as music".

The model could explain most features in the particular patient group (Griffiths 2000).

3.6 Criticism

Musical hallucinations propose some problems, starting from the fact that different phenomena and concepts other are not always recognizable from each other. First problem is the differentiation between hallucinations and pseudo hallucinations, hallucinations with and without insight. Some authors claim, that the distinction has been artificial from the beginning and there is no reliable way to diagnose pseudo hallucinations based on their definition(Zungu- Dirwayi 1999). And then there authors (see Baba et al. 2003; Terao 2000) who readily use the concept.

It remains obscure whether MHs really deserve their own disorder label (like organic hallucinosis in IDC-10) or should they be diagnosed as a special form of another disorder. CBS has been particularly suggested as a possible diagnose, as peripheral blindness is comparable to peripheral deafness and patients are typically elderly (Hori et al. 2001). On the other hand, CBS itself is not a clearly defined disorder (Fernandez et al. 1997) and adding new symptoms to an already vague diagnosis might totally terminate it's usefulness. It is also ill-suited for describing MHs because there are contradictory features, especially the unpleasantness (Griffiths 2000; Izumi et al. 2002).

There has been a discussion about the relation of musical obsessions and musical pseudo hallucinations between two research groups (Terao et al. 2000; Hugo, Zungu-Dirway et al. 2000). The debate began when Zungu-Dirway, Hugo et al. (1999) published a case report about two patients diagnosed having musical obsessions. Diagnosis was based on interviews and SPECT results showing increased temporal lobe activation. Notable feature in their study was that the patients localized the music to their heads and could control it to some extent, e.g. when asked to "get obsessed" before the imaging. Terao et al. (2000) suggested that the symptoms indicated presence of musical pseudo hallucinations whereas Hugo et al. (2000) believed these to be two OCD cases. Both have neural correlative evidence to support their claims, so debate can't be settled that way.

Pseudo hallucinations have their known defects, whereas obsessions provide a new approach to MH research. Terao's view is supported by a group study of schizophrenic inpatients that paid attention to the details of MHs (Saba & Keshavan 1997). They concluded that volitional control of the experience, which was present in Zungu-Dirway's case, could best distinguish the real from "imagined" hallucinations. Related question is can musical obsessions be considered synonymous with former term endomusia, which is still used by some clinicians[11].

Another problem, although not a serious challenge, is in differentiating hallucinations from illusions. Hallucinations (as previously defined) differ from illusions in a way, that illusions are "misinterpretations" of the modal input, a causal effect of the incoming information (Stuart 2001). Hallucinations on the other hand don't depend on sensory input. The misinterpretation can rise from the fixed properties of cognitive processes (cognitive impenetrability) or from expectations concerning the input (cognitive penetration, Fodor 1984). It is unclear, should the latter case be considered as an illusion. At least some authors seem to have some problems with distinguishing between hallucinations and illusions (Pearson et al. 2001). In the final phase of theory constructing the available evidence poses a problem. In neurology and neuropsychology there are some fundamental problems with generalizing over individual cases. In some neuropsychological publications, authors may provide quite detailed information about the structural deficits but when it comes to behavioral indicators and mental states, things get complicated. Especially considering music, the reports are almost always inadequate for making reasonable comparisons between cases (see Vignolo 2003). Even if organic damage is more accurately reported, it is not possible to get exact information about lesion's extent in brain (problem with spatial resolution). The fact, that there is a considerably small amount of patients suffering from musical deficits or hallucinations doesn't make the task any easier.

[11] Kellaris JJ, personal communication (2004).

3.7 Summary

Musical hallucinations come in various forms. As examples and hypothesis have been provided, we can sum up the diagnosis. In a historical study, 91 MH case references were found and 46 of them investigated thoroughly, mostly organic hallucinations (Berrios 1990). In statistical analysis, Berrios found that hallucinations were more common in women (80%), in patients past middle-age (mean 60, s.d. 19 years) and among the deaf (67%). Also he mentions that 32% experienced lateralized hallucinations, 40% suffered only from MHs, 35% had also tinnitus, and 73% had the insight to their hallucinations. Therefore the author argued that women might be more predisposed to hallucinatory experience and not alone to report them and that ear diseases, deafness and right hemisphere brain diseases are the other important risk factors to MHs.

Berrios' review was by no means conclusive to MHs. All the described cases made up a very heterogeneous group and it seemed problematical to create a valid standard for diagnosing MHs (Fischer 2004). This view was recently challenged by Hermesh et al. (2004) who introduced a new qualitative method for gathering data about MHs. Based on their results they argue that MHs might not be so uncommon as was previously believed. Especially among patients suffering from OCD, up to 41% reported MHs. Also the other risk factors, sex and age, were questioned as it would seem that MHs are more common among psychiatric patients in both sexes and all age groups.

These two rival descriptions have not yet resolved the issue and it remains to be seen are there single or several qualitatively different MHs, induced by different causes. Some elemental properties of hallucinatory experience, insight and experienced localization, have been introduced and should be considered in diagnostic description. Some theories and models on hallucinations in general MHs in particular have been proposed, but none of them has been really tested.

4

Conclusions

> From our perspective, the issue is no longer one of generalizing theory to visual imagery's poor relation. For we now know that auditory imagery is a rich phenomenon in its own right, especially given its many ties to memory, music speech and language, to the voices of schizophrenics, and perhaps even to the inner voices of our conscious selves.
> (Smith et al. 1992:117)

A range of investigations has been introduced from several disciplines. Along the way, some hypotheses have gained confirmative evidence and some others have been abandoned. When it comes to nature of imagery, the behavioral and neural evidence bespeaks of a strong similarity between the experienced and imagined. In the more thoroughly investigated visual domain, this has been proven quite comprehensively from the low-level to higher level sensory areas (review in Kosslyn et al. 2001). In the auditory domain the same finding has been made definitely on the "higher level", the lack of reliable low level discoveries emphasizes the previously recognized difference between imagery processes in different domains. Results from several neurological examinations of hallucinating patients have shown activation patterns similar to those evoked by imagery (Griffiths 2000; Izumi et al. 2002). In the case of music, critical area seems to be the right auditory association area. Findings from these separated domains suggest that imagery experiences is "real" perception like event and not explainable in purely cognitive terms like tacit knowledge (Pylyshyn 1981). Together these findings also support the continuum hypothesis, which states that perception, imagery and hallucinations are different parts of a same process (Vogeley 1999). This hypothesis is compatible with the interaction model.

The details of neural basis are still fuzzy. One of the most initially promising findings was made by Penfield & Perot (1963, described in chapter 3.3). Had they found the neural substrate of memory? Even though the reported results where ground breaking, the experiential responses were not common among his subjects, only 40 patients out of 520 (7.7%) indicated a reminiscence after a stimulation to temporal lobes. The second issue was that the recall seemed quite random, it was unusual for one patient to have the same experiential response to an identical stimulation and above that, some of the elicited memories were not real (Loftus & Loftus 1980). It was hence concluded that the experiential response was a dream like experience and told nothing about memory (Neisser 1967 in Loftus & Loftus 1980). Even stronger argument against memory localization was provided by Penfield himself. With a patient who experienced recall in a systematic way, a strong current was applied to destroy the tissue under the stimulating electrode. The outcome was that the stimulation could no longer trigger a recall, supporting the localization hypothesis, but the person could still voluntarily recall the episode, which nullified the evidence (Custance 2001)[12].

There have been some controversial findings in neuroscience concerning musical imagery. The prime example is the activation of supplementary motor area (SMA) during imagination of music. Same sort of activation is observed during motor execution and imagery. The inference has been that this would be a result of subvocal rehearsal, signing silently to oneself (Zatorre 1999). It was already suggested based on behavioral studies that musical imagery would always be covert performance, no matter if the music is lyrical or instrumental. This view very much resembles the subvocalization theory of schizophrenia (Smith 1992), that might explain musical hallucinations at least partially. If were so hallucinations and imagery should reveal a subvocal component in brain activation. It not certain does this happen; at least the SMA activation has not been among the observed shared activated areas (McGuire et al. 2000; Copolov et al. 2000). It has been also shown that musical and verbal hallucinations produce different patterns of activation, but without knowing what to look for, the interpretation is impossible (Izumi et al. 2002). When it comes to healthy subjects, too little is currently known about the subvocalization to make comparisons, although the recent results suggest that the critical area for verbal material's subvocal rehearsal would be located in the inferior frontal gyrus, not in the auditory cortex (Nixon 2004). On the behavioral and phenomenal level, subvocalization hypothesis has also some problems. We know that some timbres and environmental sounds are quite impossible to vocalize (e.g. harpsichord and thunder, former example from Smith et al. 1992) and still we can imagine them. It has been also shown, that results from the so-called homophone judgment experiments can't be explained by subvocalization (Smith et al. 1992).

[12] These type of findings may have lead Penfield to a dualistic standpoint, voiced by his last writings in the seventies (Custance 2001).

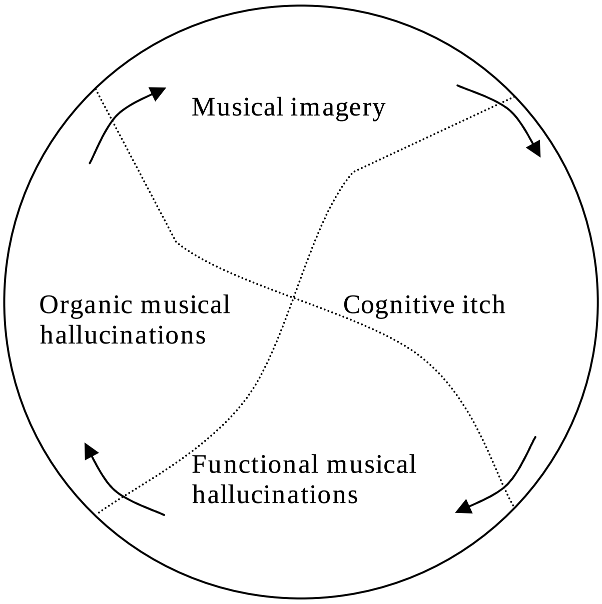

Figure 6. Ongoing musical experiences that are not currently clearly distinguishable from each other.

Cognitive itch is a fairly new topic and has neither been seriously evaluated as concept nor tested as a phenomenon in the literature. The term it self is slightly misleading, the author has originally implied that some music may have certain properties that cause our cognitive system to "itch". The metaphor compares cognitive architecture to skin in a way that the itching (triggered by stimulus properties) and scratching (mental rehearsal) only makes things worse creating a feedback loop (Kellaris 2001). I believe that this theory describes some key features of the phenomenon, but does not explain much. Giving a name to an existing and long neglected phenomenon is certainly justified but the suggestion 'cognitive itch' has some flaws. As this description is based only on modality specific stimulus, not cognitive properties, more appropriate name would be musical itch. Cognitive, sensory or auditory itch would definitely be too general suggestions. In theory, memory and rehearsal concepts seem valid, but assigning the causal role to stimulus is problematic, because it would suggest that without certain types of stimuli, we wouldn't itch at all. I'm suggesting that even if the stimulus properties do matter, the more important are the properties of music cognition embedded in our brain. Why we all have that sort of a mechanism is an intriguing question without an obvious answer.

Neural substrates of musical itch have not been examined. The ongoing experience in musical itch resembles musical imagery to a great extent, except for the fact being triggered involuntarily (Kellaris 2001). Itch and imagery could be considered equivalent unless it could be proved that we can imagine music in a qualitatively different way we experience musical itch, which no study has this far tried to examine. If we assume that subvocalization hypothesis is correct and imagery and itch are equal, itch would have an explanation, we'd only need to add an involuntary activation mechanism (trigger) for memories. Griffiths' (2000) trigger model might give a hint how this could be achieved. After that pseudo hallucinations could be described as trigger's hyperactive state, although there may be qualitative differences we currently don't know of. Real musical hallucinations might be similar to this expect for the fact that due to poor metacognition (self-monitoring) the patients could not localize the sound source correctly. Musical obsessions, in case they exist independently, could follow the same path, as more common symptoms of OCD include other types of often subvocal rehearsal (e.g. counting numbers). Concerning the neural correlates, it seems likely, that mental rehearsal of music in musical itch is based on essentially the same substrates as imagery. The only exception is the triggering mechanism that is quite fundamental to hallucinations also but what we know very little about.

The final question that the imagery and hallucination research have avoided is why. What's the general purpose of musical abilities and what's especially the use of hearing music when it's not present? This issue is hardly ever discussed in the studies, but in my opinion some theory is better then no theory at all (see Fodor 1975). Concerning 'why' questions in psychological domain I believe that biological and culture evolutionary approach is preferably, even if some (like Pinker 1994) have thought that music is of no adaptive value, only a side-effect of the general auditory faculty. Considering imagery that relies on a neural substrate shared with perception, it might be argued that it exists solely because perceptual processes happen to be exploitable and is therefore a (useful) byproduct. Still healthy people in our culture experience musical itch instead of hearing baby crying, cars accelerating or men talking, all at least as common auditory events in everyday life[13]. For musical itch and imagery, I find most attracting the proposal about music as a mnemonic aid of illiterate cultures (Sloboda 1985, see the related discussion in Cross 2001, Huron 2001 and Hauser & McDermott 2003).

[13] The term spontaneous imagery is used to refer to similar phenomenon in visual domain, but this event is not us common as musical itch in normal states of consciousness (Campbell 1996).

4.1 Models for musical cognition

Modeling musical functions and mapping them to brain regions has barely begun. In addition to Griffiths' (2000) trigger model of organic hallucinations, there are only two descriptions of the musical domain that could be accounted as models. Tramo (2001) has sketched the anatomy of music perception and performance. He has divided the auditory cortex to core, belt and parabelt areas of music processing. The core area handles "lower" (quote from the reference) processing and is connected to the belt area. The belt area (auditory association cortex) is connected to the parabelt area, thalamus, and frontal, parietal, and temporal cortex. Parabelt has further connections to other cortical areas. These connections make it possible to relate music to various properties of human behavior, including kinetics, visual perception, personality, episodic memory, emotions and expectancies. To apply this model to current findings in imagery, we must assume that the belt area activation refers to perception like experience of imagery and that input for this module comes from one of it's cortical connections, possibly frontal (Halpern & Zatorre 1999). Model is still probably too abstract to provide a starting point for serious testing and modelling.

A more elaborated modular model of music processing has also been suggested (Peretz & Coltheart 2003). Model is based on a multi-component structure of music and is supported by neuropsychological evidence. The approach is essentially functional and theoretical, the model doesn't propose neural locations for the modules, even though it assumes that the modules are localizable in nature The musical process begins with general acoustic (auditory) analysis, which feeds modules processing pitch organization, rhythm, meter (both temporal organization) and phonemes. The pitch organization is further analyzed to contour, interval and tonal information. Together these musical modules connect to emotion analysis and musical lexicon that stores representations of (instrumental) music. It is interconnected to phonological lexicon that receives input from phoneme processing. This makes it possible to attach words to melodies. Musical and phonological lexicons interact with the associative memory module to consult for nonmusical information. Musical lexicon also makes it possible to perform music, using vocal plan formation which finally leads motor execution module, like the phonological lexicon. This could be probably expanded to include motor programs for playing instruments, although not included in the model.

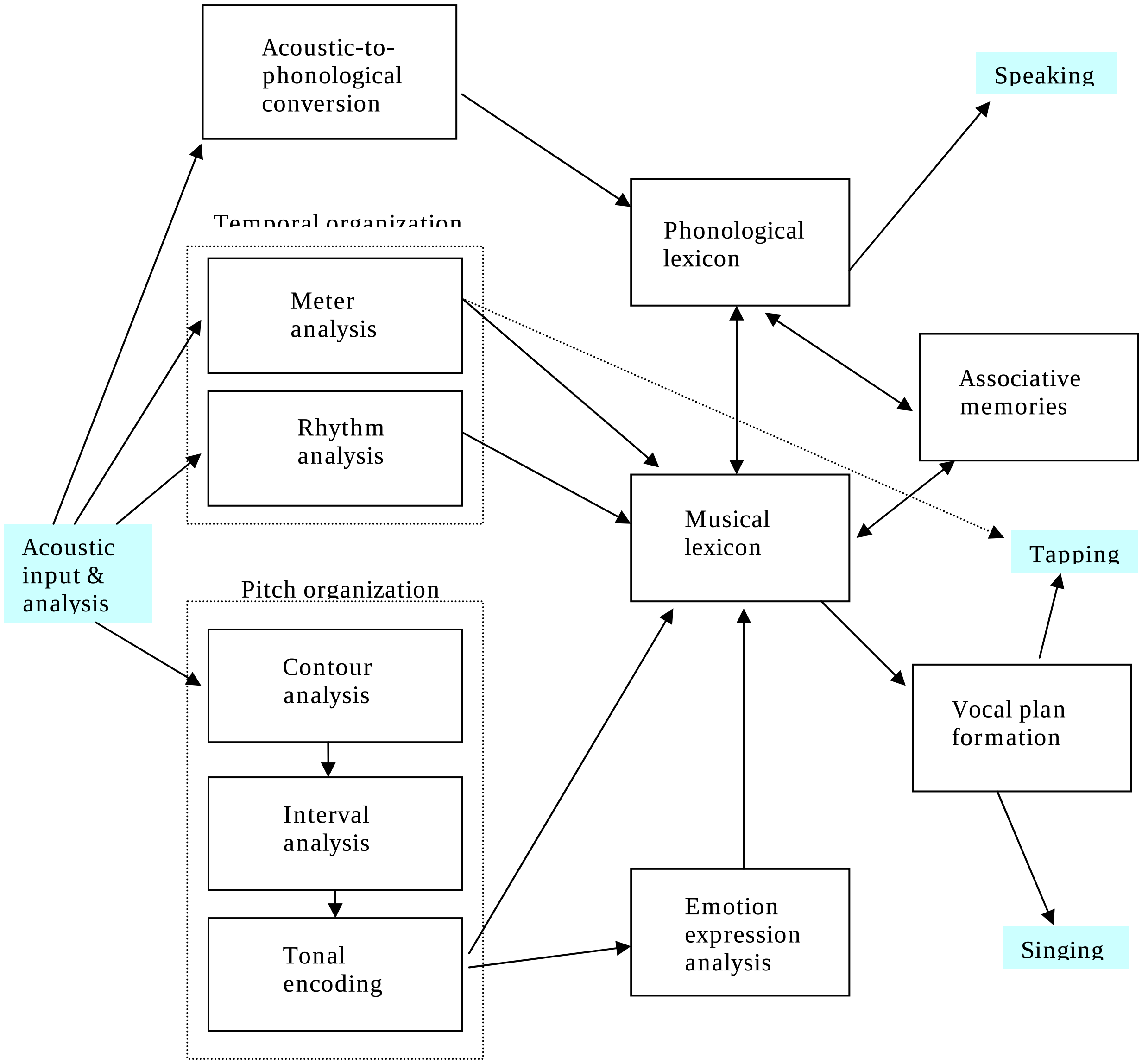

Figure 7. A modular model of music processing. Adapted from Peretz & Coltheart (2003).

This model has considered neither musical imagery (memory recall) nor neural implementation directly it must be applied to imagery with caution. Model has embedded memory storage (lexicons), but it has no descending connections. I see two possibilities to achieve recall. First would simply require a connection from the output modules to the start ofacoustic analysis, if we assume that the output could be subvocal. The other possibility would be to add a feedback from lexicon modules to “lower level” modules and a connection from lexicons to an even higher level structure (the trigger). Altogether this model is quite promising but definitely not complete.

Finally, we have the previously described Griffiths' trigger model (Griffiths 2000). It is simpler than the others, but captures some elementary properties of musical processing and is more neurally oriented. It assumes three levels, individual and pattern in segmented sound perception and encoding and recognition of patterned segmented sound. Pattern perception includes imagery, although there is no explicit definition of perception and imagery, so this model can only say that the experienced properties of imagery and perception derive from the activation of a shared process. Hallucinations were explained by a feedback mechanism between pattern and recognition modules, but it is a mystery how the imagery activates some particular sound pattern in the model.

4.2 Musical representations

If we want to consider music as cognitive structure, we must also address issues like representation encoding, storage, retrieval and maintenance, and properties of musical representations (Kosslyn 1980). There have been some initial attempts to test musical memory's retrieval and encoding functions with neuroimaging tools (Platel et al. 1997, 2003; Halpern & Zatorre 1999), but this research branch would definitely need some plausible background theories before much can be achieved. So the observed activation is generally interpreted simply as experiencing imagery. Still these distinct mechanisms are probably necessarily for hallucinations and cognitive itch as well. One considerable difficulty in imaging studies could be the use of techniques that have poor temporal resolution and may so effectively hide the different components of the process. The other major issue that increases uncertainty is the crossmodality & multi-component structure (chapter 2.4), that displays the difficulty of determining what parts of the musical experience neural investigations actually measure.

The studies of an ongoing musical experience must involve neural correlates of mental representations and computations as music must be somehow internally represented. But how this is done, remains unknown especially in musical domain. The described models are compatible with the idea of representing information possibly in modular structures, but don't explain it. On general level, one suggestion has been the audiotape recorder model (videorecorder in Loftus & Loftus 1980), but there is much evidence that it doesn't describe the human information processing very well. Even if that model was not correct, it seems that musical memories resemble the perceived music to a high degree and so the representations are also at least functionally equivalent. As long-term representations obviously don't store the auditory signal as an audiotape recorder does, they are prone to lose or replace the information, resulting in a biased playback of the record, which really happens. An alternative explanation that refers to reduced representations might be more suitable.

About two decades ago there was an active discussion about music's possible similarity to language. The most influential theory has been Lerdahl's and Jackendoff's generative theory for tonal music (GTTM), which imported some ideas from Chomskyan linguistics in form of transformational syntax to music analysis (Lerdahl & Jackendoff 1983 in Sloboda 1985). Interest in this topic has thereafter faded, but the rise of neuroscience has given new evidence on language-music –relation (see Patel 2003). Still a theory based on generative processes is preferable to the audiotape recorder model. Based on GTTM, Large et al. (1995) created a connectionist model for musical representations that could quite successfully reduce music to representations and generate them back again. But not perfectly, still something similar might be involved in human music processing, as we like Large's network, are able to recognize music and musical variations based on abstract features.

We don't currently know much about the representations. By solely observing the neural correlation of perception and imagery or hallucinations we can't address the question like representation format or its properties. This goes for imagery and hallucination studies also. This has been noted by some cognitively oriented investigators:

> While we agree with Farah (1988) that this sort of investigation cannot directly address the question of the format of mental images, and it is possible that different functional representations could coexist in the same physical substrate, our data suggest that it is unlikely that auditory images exist solely as abstracted entities divorced from their perceptual origins. (Zatorre, Halpern et al. 1996:42)

Still it should not be theoretically ruled out, that behavioral experiments in neuroscience can help to create a convincing theory of musical representations.

4.3 Expectations from future studies

> The study of neurological bases for music will not advance substantially until the categories and distinctions between musical activities made on psychological and music-theoretic grounds are taken seriously by researchers. Too often test are devised on the basis of methodological convenience rather than with precise and well-grounded musical considerations in mind.
> Sloboda (1985) 265

Neurosciences have considerably extended our understanding of musical imagery's neural basis. Nevertheless there are many open questions, as the old ones previously investigated by cognitive psychologists have not been answered. The representation formats are just one of the riddles that we don't currently know more about than we did about two decades ago. On general level, many interesting themes like music and emotions, music and language have been only under preliminary investigation in theory and practice (emotions: Blood & Zatorre 2001; language: Patel 2003). Still these issues are probably affect imagery also. The greatest expectation for future music imagery studies is the concentration on stable variables of the experience. The current holistic trend has at best separated only lyrical and instrumental music and has not given data about the imagery process itself, only about its relation to perceptual processes at gross neural levels. To answer some specific questions about underlying representations and cognitive architecture, more specified experiments should be arranged to test only single variables at a time, if possible. Musical itch might a more difficult event to capture with neuroscientific tools due to its unstable nature. It would still be interesting to try to see whether itch related activation could be reliably measured and to what extent this activation would resemble typical activation in imagery studies.

Musical hallucinations have been long investigated, but the phenomenon is still not well-understood and the studies should be continued to more accurately describe hallucinations and understand their reason. One way to achieve this might be an extensive qualitative approach, similar to GSIHMH tool suggested by Hermesh et al. (2004). If it is possible to separate musical hallucination types from each other with interviews and questionnaires, it would be natural to continue the neuroimaging studies and try to identify neural correlates of distinct hallucination types. This is naturally very challenging as the possibilities for acquiring experimental data are limited. Successful imaging could be a valuable aid in future diagnostics, as the mental experience is otherwise out of clinician's reach. It might be advisable to follow imagery studies and try to correlate activations with features of hallucinatory experience, that is, e.g. to compare dominantly instrumental or lyrical hallucinations and in patients without hearing loss to compare hallucinations to the perception of similar music. Success in this field of research might greatly improve patients' possibilities to get useful treatment and to cope with their condition. Musical hallucination research may in time profit from the more prominent research of verbal hallucinations. Final methodological tip concerns neurology and psychiatry. If we wish to learn more form single cases, more accurate descriptions of musical deficits and hallucinations are required as the auditory domain and musical functions are very complex.

The existing music processing models are far from complete. In future we would hopefully have a model that could be able to account for synesthesia (seeing or feeling music), imagery, musical itch, the hallucinatory experience in organic or functional cases and other musical phenomena. To explain the imaging results theories must be neurally localizable and describe the neuroplasticity in CNS related to music. To achieve this we will probably need to know more about cognition and brain functions in general. Good theories and hypotheses are needed and (like Patel's shared syntactic integration resource hypothesis) may prove valuable in the future.

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