Final Report
NWO-PIONIER Project
'*Music, Mind, Machine*'

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0 Preface: The MMM Experience

The ubiquity of music is undisputed. Medieval astronomers detected the music of the spheres. Theologians of all conceivable denominations agree that an eternal stream of sacred musac is played in heaven, although they disagree fundamentally about the selections being offered. Biologists tell us that many animals make music because that puts them (the animals, that is) at an evolutionary advantage, just as their colourful plumage and elaborate nest building do. It can be no accident that poets have envisioned the musical composition of nature—as, for instance, S. T. Coleridge did in his poem *The Eolian Harp* when he asked:

> And what if all of animated nature
> Be but organic harps diversely fram'd
> that tremble into thought.

And finally, music counts as a certified 'human universal', an inherent and heritable characteristic of human nature: contrary to the old German folk wisdom, 'böse Menschen' do have their songs—usually lots of them.
Music appears to be everywhere and everywhen. A comprehensive theory of music will therefore necessarily approach the ideal of theoretical physics, the Theory Of Everything, or TOE for short. I found the original proposal that described the *Music, Mind, Machine* project highly promising in this respect as it contained the grains of a *very* general theory of music; if not quite a TOE, then at least a Theory Of *Nearly* Everything, or TONE for short.

Understandably, therefore, I felt flattered when, at some point in the course of the project, I was invited to join the MMM-team as an external adviser. In harmony with Coleridge's fascinating metaphor I "trembled into thought", and I confess that I have tremendously enjoyed the three years that allowed me to reverberate empathically to the creative vibrations of the MMM-team.

This is the final report of the NWO PIONIER Project Music, Mind, Machine. As an invited member of the team I am not the person to evaluate, at this time and place, what went right and what went wrong or what has been accomplished and what hasn't, except by acknowledging that MMM has had its fair share of successes and failures. Putting it all together, however, the contents of this final report should convince even the most severe critic that the project has been a success on many accounts. The number and scope of the projects completed, the measurable output in terms of publications, the technical and methodological items delivered, and the sundry activities by the MMM-team described here, are substantial by any standard and as such will be a source of satisfaction and pride, not only to the investigators, but also to NICI, KU Nijmegen and NWO.

Let me briefly elaborate on what I personally have gained from the MMM-experience.

Much as I have tried to internalize the deep structure of the TONE set by the MMM-team I must admit that thus far I have not yet traveled far enough. But I am happy that I understand at least some of the ramifications. Each time I sit down to re-interpret one of the problems that have haunted me throughout my career, the wisdom of MMM's TONE invariably appears to offer a new and deeper insight. The following two examples, one old and one recent, will illustrate this.

The first problem is connected with what I have referred to, many years ago, as 'timing in temporal tracking'. Temporal tracking is about the precision with which people can synchronize their movements to the musical beat, constant or variable, and with the systematic variations in their performance. With sufficient insight it should be possible to build a true-to-life model, a robot, say, that could, for instance serve as a dance partner.

The underlying issue here is what may be called the *Coppelia tangle*. Coppelia, as we know, is a ballet about a life-sized mechanical puppet of that name in the shape of a ballet dancer—and an extremely attractive one at that! Coppelia is used by her creator to seduce naive young men... as the saying goes, it takes two to tangle.

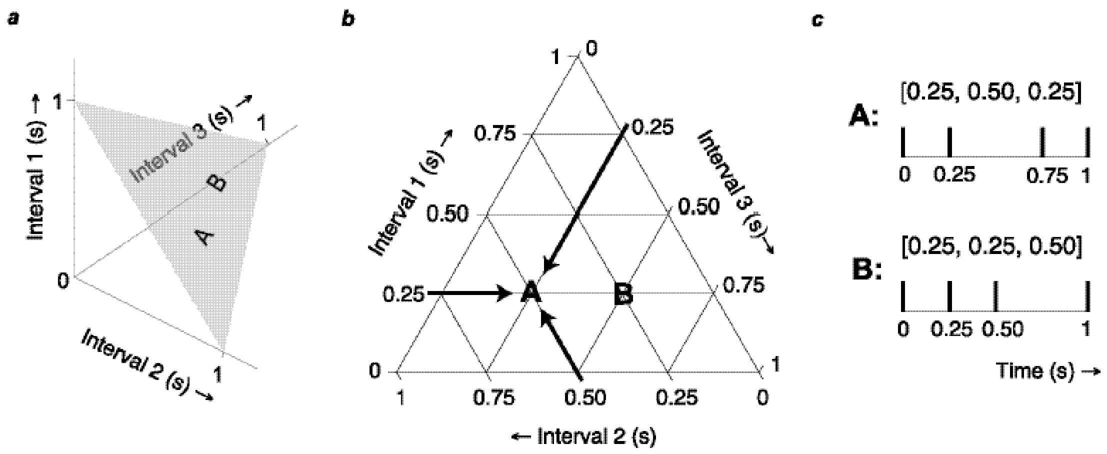
More specifically, the Coppelia tangle is the knotty situation in which the *prima donna* of the ballet finds herself: a dancer pretending to be a clockwork pretending to be a dancer.

Imagine how relieved I felt when, after decades of struggling with this mind-boggling recursive problem initially posed in one of the hair-raising tales of E. T. A. Hoffmann, I understood that the MMM-team had been able to transform the problem into a simple and elegant empirical paradigm. They showed that the Coppelia tangle reduces to an empty ballet shoe and a Turing Test to decide whom the shoe fits.

The second problem is even more complicated, but again the MMM-team has come up with an incontestable solution—this time even without being aware of the problem in the first place, which I take as a sure sign of the universal validity of their TONE.

A few years ago, in 1999 to be precise, the physicist Julian Barbour published a book with the title *The End of Time*, for me as a chronopsychologist an alarming title, to say the least. Barbour's argument rests on the idea of configuration space, an abstract space of super-high dimensionality in which each possible state of the universe is represented by one single point. Each point in this configuration space, and consequently each distinct state of the universe, has a characteristic probability of becoming actual. Since the likely succession of actual states is determined only by the timeless probability density function over the entire configuration space, time vanishes! Presto!

To my relief the *rhythm triangle* that Peter Desain and Henkjan Honing have so diligently extracted from their studies on rhythmic categorization (see Figure on opposite page) offers a simple explanation for Barbour's vanishing trick. Their triangle represents in fact the configuration space of a very simple universe containing only three ‘particles’, viz. intervals 1, 2, and 3. Moving from one point in this configuration space to the next is indeed, as in Barbour’s case, a matter of the probability density over all possible intervals 1, 2, and 3. But, rather than being lost, time in this configuration space is an *intrinsic* property of the points in this space. Each point of that space represents a state of the rhythmical universe, that is, a temporal pattern consisting of three intervals. Armed with this insight it quickly transpires that this is precisely the basis of Barbour’s vanishing trick. Actually Barbour admits as much when he writes: "All objects encode to greater or lesser degree information about what we call their history.” Upon which time reappears, not as a structural dimension of space-time, but as a relation between events: time has a history.



*Rhythm space of all 3-interval temporal patterns adding up to one second duration (**a**), ternary plot (**b**), and two example patterns (**c**) (see Desain & Honing, 2003).*

Unlike time, unfortunately, MMM is coming to an end. But the work will go on, we are told. It is appropriate, therefore to ask where this kind of research should lead us next. The imminent separation of the main characters of the team may perhaps lead to a *ritenuto*, but I am convinced that sooner, rather than later the MMM-team, *some* MMM-team will be able to continue *a tempo*.

When that day arrives, I would sincerely hope that the investigators will extrapolate their findings further towards the domain of music as a cultural phenomenon. In his recent book *The Blank Slate*, Steven Pinker pointed out that "a growing number of maverick scientists are looking to evolutionary psychology and cognitive science in an effort to reestablish human nature at the center of any understanding of the arts. [...] A good grasp of how the mind works is indispensable to the arts and humanities.” This remit, in my opinion, more than justifies continuing the path traveled by MMM so far on the way to—quoting Pinker again—"a new convergence of exploration of the human condition by artists and scientists.”

John A. Michon
Leiden, 14 August, 2003

Meeting a friend in the corridor, Wittgenstein said: "Tell me, why do people always say it was natural *for men to assume that the sun went round the earth rather than that the earth was rotating?" His friend said: "Well, obviously, because it just* looks *as if the sun is going round the earth." To which the philosopher replied, "Well, what would it have looked like if it had looked as if the earth was rotating?"*

Tom Stoppard, *Jumpers*, 1972

1 Introduction and overview

This final report gives an overview of the project '*Music, Mind, Machine*' that was funded from March 1997 until September 2003 by the PIONIER program of the Netherlands Organization for Scientific Research (NWO). Building a project and group of this size has been both difficult and rewarding. The content of the research was concerned with the computational modeling of music cognition, focusing on the temporal aspects of music perception and performance. A variety of studies were realized, firmly establishing a methodological basis for music cognition research, as well as gaining new insights in the domain of rhythm perception and production.

In this report we will summarize the initial aims of the research, introduce the members of the team without whom the work would have never happened, followed by a description and interpretation of the main scientific results. Next, an overview is given of the studies arranged according to the structure of the original proposal, as well as a listing of scientific output and activities. We close with some thoughts on the future of this line of research.

We would like to express our thanks here to the advisory board for their enthusiasm and support. Without the help of various departments and services of KU Nijmegen, the project would have been impossible to realize. We are very grateful for the support of NWO (GW and MaGW), NICI/KU Nijmegen and UvA, STW, EU-IHP, and some smaller funds (see Section 9 for an overview)[1].

Peter Desain and Henkjan Honing
Nijmegen / Amsterdam, September 2003

[1] All fundamental research was funded by NWO, but applied work that elaborated on it was done with help from other funds (like STW, MOSART). We report here on the overall results, and indicate the other sources where appropriate.

2 Initial aims

The aim of the research program was to investigate music perception and performance using an interdisciplinary approach that builds on musicology, psychology and computer science – hence the name *Music, Mind, Machine* – to better understand music cognition as a whole. By starting from the margins where the approaches of musicology, psychology and computer science overlap, our research aimed at discovering solutions for problems which had proven to be unsolvable in a mono-disciplinary approach. We envisioned the method of *computational modeling* to be central in realizing this aim. The main idea of this method is to start with hypotheses from music theory, to formalize them in the form of an algorithm, to validate the predictions from this theory with experiments (using methodology from experimental psychology), and, often, to adapt the theory and computational model accordingly (using tools from computer science). In other words, theories are first formalized in such a way that they can be implemented as computer programs. As a result of this process, more insight is gained into the nature of the theory, and theoretical predictions are, in principle, much easier to develop and assess. With regard to computational modeling of *musical knowledge* –a secondary topic in our research program– the theoretical constructs and operations used by musicologists are subjected to such formalization. Conversely, with computational modeling of *music cognition* –the primary topic– the aim is to describe the mental processes that take place when perceiving or producing music, which does not necessarily lead to the same kind of models.
As such, a computational model that mimics human behavior is not enough, being more a starting point of analysis and research than an end product. And although computational modeling was by the time the project started already a well-established method in many fields, the aim of the research was to fulfill the potential of this methodology: to narrow the gap between the disciplines involved in music cognition research. We will describe some of these studies aiming to bridge between disciplines in more detail below, after first giving an outline of the structure of the project.

3 Organization

3.1 Structure of the project

The structure of the project was conceived adopting three perspectives: the music domain itself, the computational modeling methodology, and their application.

The *domain studies* dealt with the empirical basis, the construction and validation of computational models of music cognition, concentrating on the perception and production of musical time and temporal structure. The starting point for all these studies were constructs from music theory and performance practice that were approached using methods from AI and experimental psychology.

In the *methodological studies* the emergent methodology of computational modeling was made explicit. The issues addressed ranged from the fundamental problems of the methodology of computational modeling to detailed technical and practical solutions.

Next to basic research in music cognition, we set out to apply our findings as well. To further develop prototypes and *applications*, we acquired additional funds, including one from NWO-STW on automated music transcription and an European grant on music technology (MOSART). We will only briefly report on them here.

3.2 Advisory Board

Mr. H. Heuvelmans (Gaudeamus, Amsterdam)
Prof. Dr. W. J. M. Levelt (KNAW, Amsterdam; Max Planck Institute, Nijmegen)
Dr. L. P. A. S. van Noorden (European Commission, Brussels)
Prof. Dr. Ir. R. Scha (University of Amsterdam)
Prof. Dr. R. F. Wolpert (University of Arkansas)

3.3 Staff[2]

3.3.1 Advisory Staff

John A. Michon *(senior advisor, since 2000*) is emeritus professor of psychonomics at Leiden University. His research, over the past forty years, has covered a variety of areas in psychophysics, cognitive psychology, ergonomics and the social sciences. Early on he became professionally interested in the intricacies of rhythm and synchronization. This resulted in a method for measuring mental load, using rhythmic tapping, which gained appreciable popularity and gave rise to his PhD dissertation *Timing in Temporal Tracking* (1967) in which synchronization and continuation were modeled in terms of linear systems theory. This study is now considered by some a 'classic' in the field. His later work on the temporal aspects of cognition and behavior has contributed to the revival of time and timing as 'mainstream' topics in cognitive psychology. It earned him the august position of president of the International Society for the Study of Time (1983-1986) and a doctorate *honoris causa* from the Université de Liège (1995). Most recently he has been focusing on the information processing characteristics of relational representations of time.

[2] Quite a number of scientists and technologists were involved in the MMM project. We will list them here in alphabetical order. When they were supported by other than NWO-Pionier funds this is indicated behind their name.

Dirk-Jan Povel *(senior advisor, until 2000)* has been involved for over twenty-five years in theoretical and applied research related to speech perception and speech production, the perception of temporal patterns and musical rhythms, and the production of serial motor patterns. His applied work was mainly concerned with various aspects of the acquisition of speech by the deaf, leading to the development of the Visual Speech Apparatus, a system that provides visual information and feedback about sound in a form suited for teaching speech to hearing impaired children. More recently he has been doing research in the field of music cognition, questioning the contribution of melodic and harmonic factors in the formation of mental representations of music. Currently he is studying the on-line processes of music perception to discover the perceptual mechanisms listeners' use in coding music.

3.3.2 Scientific Staff

The MMM group in 1997 (photo by Margriet Smulders).

Rinus Aarts *(PhD student)* studied music technology in Utrecht, switched to computer science in Twente, and graduated in cognitive psychology at the KU Nijmegen in December 1996. His major strength lies in the development of cognitive models that can imitate human behavior, and testing these models experimentally. He has experience working in a team of international graduate students and researchers, as he spent ten months at Penn State University for his internship. Under the guidance of David A. Rosenbaum, he worked on a model for the control of human reaching movements. This acquainted him with many theories in the field of human motor control research. In 1999 drs. R. Aarts joint a software company in Nijmegen.

Torsten Anders *(junior researcher; partly supported by MOSART)* studied musicology and theology in Berlin, switched to composition in Weimar, where he specialized in electroacoustics (with a focus on computer assisted composition). He studied with Wolfgang von Schweinitz, Michael Obst, Hans Tutschku, and Robin Minard. He composed multichannel tape pieces and sound installations (commissioned by Designzentrum Thüringen, 1999, and Gartenbaumuseum Erfurt, 2000). He received a scholarship of the Thüringer Komponistenverband 1999 and 2000. In October 2000 Torsten Anders joined the MMM group as a Lisp programmer. In 2002 he started a PhD in music at the Sonic Arts Research Centre at Queens University Belfast (UK).

The MMM group in 1998 (photo by Margriet Smulders).

Ric Ashley *(senior researcher)* is Associate Professor of Music is at Northwestern University in Illinois, USA, one of the foremost Schools of Music in the USA. He earned his D.M.A. at the University of Illinois in composition and music cognition, and also studied at the Rijksuniversiteit Utrecht in musicology (with Jos Kunst) and sonology (with Paul Berg and G. M. Koenig). Dr. Ashley is well known for his research and publications in music cognition, music theory, and computer music, and is on the Editorial Board of the journal Music Perception. He carries out research on how conductors communicate musical expression to ensembles and how jazz musicians work together in ensemble performance and participated in the expressive timing project.

Peter Desain *(co-director / senior researcher)* has a background in mathematics (TU Twente) and psychology (KU Nijmegen). His PhD research was conducted at the music department of City University in London on the topic of structure and expressive timing in music performance. After a KNAW postdoc fellowship at NICI and a year as visiting scientist at the IBM Watson Center in New York he received the NWO PIONIER grant. His long-term research goal is to establish a thorough methodology for computational modeling of music cognition in which the contributions of the three disciplines of psychology, musicology and computer science are tightly interwoven.

The MMM group in 1999.

René van Egmond *(postdoc)* has a background in Systematic Musicology, Acoustics, and Psychoacoustics (University of Amsterdam). He received his PhD at the Department of Experimental Psychology at the KU Nijmegen. He worked as a university post-doctoral fellow at The Ohio State University. His main research topics are melody and tonality perception. In 2001 Dr. R. van Egmond accepted a permanent position as researcher at University of Delft.

Hank Heijink *(PhD student)* studied computer science at the KU Nijmegen from 1991 to 1996. During these studies he focused on theoretical informatics in particular formal languages, complexity theory and functional programming. Since May 1997 he has been working in the MMM group. His musical activities have included guitar-playing, oboe playing, playing drums and percussion, and lately, lute playing. In 2000 he completed his classical guitar studies at the Brabant Conservatorium in Tilburg. He received his PhD in 2002. He started a conservatory study in Den Haag, playing the lute.

Henkjan Honing *(co-director / senior researcher; partly supported by UvA)* has a PhD in music from the City University, London (1991) on the representation of time and temporal structure in music. Before this he studied at the Institute for Sonology (UU) and at the Center for Computer Research in Music and Acoustics, Stanford University, USA. He was a Research Fellow of the KNAW at the Institute for Logic, Language and Computation (ILLC), University of Amsterdam (1992-1997). His aim is to develop his approach to the computational modeling of musical knowledge, working towards a science of music in which not the score but the performance is the primary object of research. Also he was responsible for the technology transfer and the industrial contacts of the PIONIER project.

The MMM group in 2000 (photo by Margriet Smulders).

Kathleen Jenks *(stagiare KU Nijmegen)* received a bachelor's degree in clinical psychology at the University of Wisconsin Oshkosh, USA in 1984. After working for several years in Ohio, managing a residence for the mentally retarded and developmentally disabled, she moved to The Netherlands to study Neurological and Rehabilitative Psychology in Nijmegen. During her studies she is working as a teaching assistant, giving work groups on statistics and methodology, and is a research assistant for the medical school. She is currently working towards her master's thesis in the MMM group. The topic of her thesis is an EEG study on Omission Evoked Potentials in rhythm perception.

Chris Jansen *(junior researcher; supported by STW)* received his Master's degree in experimental/cognitive psychology at Nijmegen University in 1995. During the academic year 1994/1995 he did a research internship at Pennsylvania State University (USA), working on a computational model on movement planning. After a short career in computer programming he was enrolled in a PhD program at the Human Movement Science department at the Free University Amsterdam for about

2 years. The topic of research was learning behavior in tapping polyrhythmic patterns. In March 1998, he joined the MMM group for participating in an STW project on quantization of rhythmic patterns. In 2000 drs. C. Jansen took a position at the IPO in Soesterberg.

The MMM group in 2001 (photo by Herbert van der Sluis).

Marijtje Jongsma *(postdoc)* studied neuro-psychology at the KU Nijmegen (1990-1995). After receiving her master's degree, she briefly worked as a research assistant at the Cognitive Neuroscience Unit, Westmead Hospital, Sydney, Australia (1996). From 1997 to 1999 she was a PhD student at the department of Anaesthesiology, KU Nijmegen. She was a researcher for the STW project on determining depth of anaesthesia (1999-2001). From may 2001 – till September 2002 she conducted her research as a postdoc at the MMM Group, and currently she works at the NICI, Department of Biological Psychology, and collaborates with the MMM group.

Stéphane Rossignol *(postdoc; funded by MOSART)* has a PhD in music and signal processing from the University of Jussieu, Paris; from IRCAM - Centre Georges Pompidou, Paris; and from Supélec (engineer school), Metz (1996-2000). The topic was the segmentation and the indexation of acoustic signals. This work was supported by France Télécom Rennes. Before this he studied electronics and signal processing at the University of Rennes (1989-1994), astronomy at the University of Nice (1994-1995), and signal processing again at ENSIETA (engineering school), Brest (1995-1996). He joined the MMM group in November 2000 as a postdoc in order to study vibrato. This work was supported by the European MOSART project.

Its aim was to study timing aspects of vibrato (as well during the notes, or "steady state parts", than during onsets, or "transitions between notes"), and to provide models of the vibrato useful for music synthesis and composition.

The MMM group on a day out in the zoo in 2002.

Makiko Sadakata *(junior researcher)* studied composition at the Kyoto City University of Arts in Japan as an undergraduate student. She received her Master's degree in musicology (the psychology of music) from the same University in March 2002. Since April 2002 she has been working in the MMM group as a junior researcher. Her interests include rhythm perception and production, the relation between them and the effect of cultural background and language.

Erwin Schoonderwaldt *(junior researcher; supported by the VU)* studied experimental physics at the University of Amsterdam, with as main subject material physics. For his graduation he has done an internship at the Netherlands Energy Research Foundation (ECN) in the business unit Solar & Wind. His scientific interest in music originates from his hobby: playing the violin and the viola. He worked on the vibrato project, a co-operation of MMM and the Faculty of Movement Science from the VU Amsterdam. In this project timing aspects of vibrato are studied by examining the co-ordination of the movements of the performer. Currently he continues his research at KTH, Stockholm.

Ilya Shmulevich *(postdoc; supported by SION)* received his Ph.D. degree in Electrical Engineering from Purdue University, West Lafayette, Indiana, USA in August 1997. His area of specialization is signal processing. His research interests include: non-linear signal and image processing, theory of stack filters, monotone Boolean functions, lattice theory, mathematical morphology, algorithmic information theory, complexity of finite and infinite sequences, music pattern recognition and computational modeling of music perception. He also worked at the Signal Processing Laboratory at Tampere University of Technology, Tampere, Finland in 1990-1991. Whilst at Purdue University, he taught various math courses in the Mathematics Department from 1993 to 1997. Additionally, he was an instructor at the Gifted Education Resource Institute at Purdue University from

1994 to 1997, where he taught courses on Electrical Engineering and Computability Theory. Ilya is now working at the Tampere University of Technology, in Finland.

The MMM group in 2002 (photo by Herbert van der Sluis).

Huub van Thienen *(computer scientist; partly supported by STW)* obtained a M.Sc. in Applied Mathematics from the University of Twente in 1985. After his graduation, he became member of the Esprit SEDOS research project, where he was mainly involved in the design of a coherent tool-set to support the formal specification language Lotos. In the fall of 1987 he joined the Faculty of Computing Science of the KU Nijmegen, where he worked with Prof. Boute and others on the development of declarative languages and methods for the description of hybrid systems. In 1994, he obtained his Ph.D. from the KU Nijmegen on a thesis on the use of the declarative language Funmath for the design and analysis of discrete dynamic systems. From 1992 to 1997 he was assistant professor of Informatics for Technical Applications at the Faculty of Computing Science of the KU Nijmegen. Early 1998 he joined the MMM group. In 2000 he took up a post in an ICT company.

Renee Timmers *(PhD student)* studied systematic musicology at the University of Amsterdam and did her PhD in music psychology with the Music, Mind, Machine group of Peter Desain and Henkjan Honing, NICI, University of Nijmegen. She teaches music psychology at the Sonology department of the Royal Conservatory of The Hague and has been working as a postdoc researcher at DIST (University of Genova) and OEFAI (Vienna). She will visit Northwestern University in Evanston to do research on ornamentation and emotion. Her main research interests are performance of music and the perception, representation and memorization thereof.

Luke Windsor *(postdoc)* studied music and music psychology at City University in London where he gained his PhD in Music Analysis in 1996. He has authored articles on rhythm and meter in music, timing and dynamics in musical performance, and the analysis of electro-acoustic music. Before joining the group, he worked as a Visiting Lecturer in Psychology of Music (City University), as a Research Assistant on two projects investigating musical expression, and as coordinator of a distance learning course in Psychology of Music (University of Sheffield, UK). His practical musical interests include free improvisation and collaborative composition. He has now left the project and is a Lecturer in the Department of Music, University of Leeds.

3.3.3 Supporting Staff

Gerard van Oijen *(electronic engineer)* studied electronics at the MTS in Tiel. Since 1982 he has been associated with the Psychology department at KU Nijmegen as an electronics engineer (both hardware and software), designing and building equipment for experiments with humans and animals. Next to his work he likes gardening, cycling, and enjoying nature.

Yvonne Schouten *(secretary)* after two years at ENKA Glanzstoff bv Arnhem as a textile analyst, has worked for Nijmegen University since 1982, first in the Multimedia Centre, from 1984 to 1986 as an archivist at the Media Group and from 1986 as secretary of the Mathematical Psychology group at NICI. Her secretarial responsibilities have included support for the MMM-group from the beginning of the project.

Paul Trilsbeek *(music technologist; partly supported by STW)* studied Sonology at the Royal Conservatory in The Hague, where he graduated in May 1997. He joined the MMM group in February 1998 as a music technologist for the STW project on quantization. Besides that he is currently also doing research on tempo and expressive timing in Beatles songs, and working on projects for making some results of the group's research available via web demos and applications. In his spare time he likes to compose pieces of electronic music and to play the guitar.

4 Summary of results and brief evaluation

The original proposal made to NWO in 1996 was an ambitious and wide-ranging research plan that aimed at combining expertise from a variety of disciplines having their basis in the humanities, the social and the natural sciences. This width was also reflected by the support from NWO: both the *MaGW* (Behavioral Sciences) and *GW* (Humanities) research councils funded the research.

The outcome of the project cannot be stated in a few lines. There is no single invention or breakthrough to focus on (despite e.g. the repeated request by journalists to make a '*Musical Hit Machine*'). Our intention has always been to create a firm basis of methodology for the domain. The various studies have build on this, step by step, and we have concentrated on developing new connections and links. Though a slow and tedious process by nature, we have been rewarded on occasion, e.g. when other researchers build on our work and parts of our material are used in music cognition courses worldwide.

Music cognition still being a young field and few journals being dedicated to it presents a challenge to publish in a wide variety of peer-reviewed journals dedicated to the disciplines involved. This was not always a straightforward matter, to put it mildly. Looking, however, at the overall output of the project (see Section 6.2) we are proud to see that we succeeded: about 20% was published in music, 45% in psychology, and 35% in computer science or technology-related journals.

In a number of studies a synergy between the three disciplines has led to novel results. In most projects, however, two of the three disciplines were involved.

An example of all three disciplines successfully collaborating is the *Grace Note* study (see Section 5.1.2). This study started with a music theoretical investigation on ornaments in music performance, classifying and formalizing the hypothesis found in the relevant literature. Then an empirical study was designed, with a large group of expert pianists involved in the experiment using the MIDI grand piano of our lab. This study revealed the regularities in timing of ornaments, partly as predicted in music theory, but also showed the important influence of global tempo, a parameter lacking in most music theoretical accounts. Finally the results were incorporated in a computational model that allowed automatic deletion or insertion of grace notes in a real performance, adapting the context (i.e. the surrounding melody notes and accompaniment) accordingly. Besides demonstrating the empirical results and the model, it served as a prototype editing tool for music performance, as such making a successful link from basic to applied research (see our website for an elaborate demo).

Not all studies had the expected outcome. Sometimes expectations proved unrealistic, sometimes were so specific that we were unable to put them to a realistic test. At other times unexpected lines of research emerged. For instance, our older work on quantization received an exiting impulse when it was complemented with an elaborate series of experiments on *categorical rhythm perception* (see Section 5.3.2). This substantial study investigated how listeners perceive discrete rhythmic categories while listening to rhythms performed on a continuous time scale. This was investigated by considering the space of all temporal patterns (all possible rhythms made up of three intervals) and how these are partitioned perceptually into categories, i.e. where the boundaries of these categories are located. This process of categorization was formalized as the mapping from the continuous space of a series of time intervals to a discrete, symbolic domain of integer-ratio sequences. The methodological framework adapted concepts from mathematics and physics (such as convexity and entropy) that allowed for precise characterizations of the empirical results. As such this study is an example of a successful bridge between formalization and experimental psychology. To date not all results of these recent experiments have been published as yet. Also we are facing the important challenge to connect with these empirical data and their formal characterization to a computational theory of rhythm perception and production. This constitutes an important part of our future research effort.

The study on *symbolic and subsymbolic processing* (see Section 5.2.3) also took an unexpected turn as we discovered how a very simple model can relate data from rhythm perception and production experiments and explain their surprising difference. A puzzling incongruence, which was thought to offer counterevidence to recent theories that postulate an intimate link between perception and action, now no longer plays this role.

With the exception of the *cognitive modeling language* (see Section 5.2.1) all originally proposed studies have been completed – or are about to –, and have resulted in a substantial number of scientific publications. While some of the topics have only been so far reported in international peer-reviewed proceedings, journal versions of these papers are currently under review or revision, or are in press. In addition a number of unplanned studies (see Section 5.3) were realized, some of which may become central to our future research.

Below we summarize the scientific output of the project in more detail, arranged by topic as specified in the original proposal.

5 Detailed overview of the results

5.1 Domain studies

The domain studies deal with the empirical basis, the construction and validation of computational models of music cognition, concentrating on the perception and production of musical time and temporal structure. The starting point for all the studies are constructs from music theory and performance practice that are approached using methods from AI and experimental psychology.

5.1.1 Beat induction

Beat induction is the process in which a regular isochronous pattern (the beat) is activated while listening to music. This beat is a central issue in time keeping in music performance. Also for non-experts the process seems to be fundamental to the processing, coding and appreciation of temporal patterns. The induced beat carries the perception of tempo and is the basis of temporal coding of temporal patterns. Furthermore, it determines the relative importance of notes in, for example, the melodic and harmonic structure. The study entailed an elaboration and comparison of a large set of computational models for beat and meter induction stemming from different computational paradigms, most notably rule-based and memory-based models.

Mechanical shoe used to demonstrate models of beat induction.

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Desain, P. and Honing, H. (1997) Computationeel modelleren van beat-inductie. *Informatie* 48-53. ISSN: 0019-9907.
Desain, P. and Honing, H. (1999) Computational Models of Beat Induction: The Rule-Based Approach. *Journal of New Music Research* ISSN: 0929-8215.
Zaanen, M., Bod, R. and Honing, H. (2003) A memory-based approach to meter induction. *Proceedings of the ESCOM*.

5.1.2 Perception and production of grace notes in music performance

Within the field of music cognition there is a theory, derived from motor control research, which states that the timing of a piece of music is invariant over tempo or, in other words, that the relations between successive time-intervals remain the same over different tempi (relational invariance). Several researchers have investigated whether this timing profile can be predicted from the musical structure of the score. Conflicting evidence has been found regarding the theory of relational invariance, and in this project we sought to investigate the concept of relational invariance by looking at the grace notes. We found that, although grace notes in certain structural categories are consistently played longer than grace notes in other categories, the major influence on grace note timing seems to be stylistic. Moreover, we found that grace notes of a specific type indeed get longer as the tempo decreases, while others retain approximately the same duration. We consider this as strong evidence against the notion of relational invariance across different tempi.

Timmers, R., Desain, P., and Honing, H. (2000). Timing of grace notes in piano performances of a Beethoven Theme. *Proceedings of the eighth International Workshop on Rhythm Perception and Production*. Castleton.

Timmers, R., Ashley, R., Desain, P., Honing, H., & Windsor, L. (2002) Timing of ornaments in the theme of Beethoven's Paisiello Variations: Empirical Data and a Model. *Music Perception*, 20 (1), 3-33.

Timmers, R., Desain, P., Honing, H., and Trilsbeek, P. (2002). Introducing a model of grace note timing. In *Proceedings of the Workshop on Music, Motor Behavior and the Mind*. Ascona, 32.

Windsor, W. L., Aarts, R., Desain, P., Heijink, H., and Timmers, R. (2001) The timing of grace notes in skilled musical performance at different tempi: a preliminary case study. *Psychology of Music*, 29, 149-169.

Windsor, W. L., Desain, P., Honing, H., Aarts, R., Heijink, H., and Timmers, R (2000) On Time: The influence of Tempo, Structure and Style on the Timing of Grace Notes in Skilled Musical Performance. *Rhythm Perception and Production* Lisse: Swets & Zeitlinger

Windsor, W. L., Desain, P., Aarts, R., Heijink, H., & Timmers, R. (2001). The timing of grace notes in skilled musical performance at different tempi: a case study. *Psychology of Music, 29,* 149-169.

5.1.3 Separating the components of musical expression

This project takes as its starting point the existing efforts of cognitive scientists to produce computational models that mimic human performers. We are currently in the final stages of developing a method to fit these predictions to data from human performances. This method will allow us to evaluate the model systematically, and to optimize the fit between model output and human data. The human data for this study have been recorded and archived and the model has been re-implemented to facilitate the optimization and evaluation process. This project is part of a larger study that aims to separate and identify the different kinds of musical structure which influence expression in performance. It has not yet been completed.

Desain, P. and Honing, H. (1997) How to evaluate generative models of expression in music performance. In *Isssues in AI and Music Evaluation and Assessment*. International Joint Conference on Artificial Intelligence., 5-7. Nagoya: Japan.

Desain, P. and Honing, H. (1997) Structural Expression Component Theory (SECT), and a method for decomposing expression in music performance. In *Proceedings of the Society for Music Perception and Cognition Conference*., 38. Cambridge: MIT.

Penel, A., Desain, P., Maris, E., and Windsor, W. L. (1999) A decomposition model of expressive timing. In *Proceedings of the 1999 SMPC*, 21. Evanston.

Penel A. (2000) Variations temporelles dans l'interpretation musicale: processus perceptifs et cognitifs. Unpublished PhD Thesis. Université Paris V.[3]

[3] The research for one chapter of this thesis was conducted while A. Penel visited the MMM group.

5.1.4 Continuous modulation of musical parameters

This study is one of the few attempts to investigate continuous expressive modulations in music performance. A number of experiments have been conducted. The purpose of these experiments was to investigate the relation between vibrato, musical instruments, and global tempo. We developed new techniques to extract these continuous modulations from audio data. In addition to its contribution to the field of music cognition research, it will be used to make synthesizers more intelligent with respect to their implementation of vibrato on generated or sampled signals. This project is in its final stages.

Desain, P. (1999) Vibrato and portamento, hypotheses and tests. *Acustica* 348.

Desain, P. and Honing, H. (2000) Modeling vibrato and portamento in music performance. *Bulletin of the Council for Research in Music Education*.

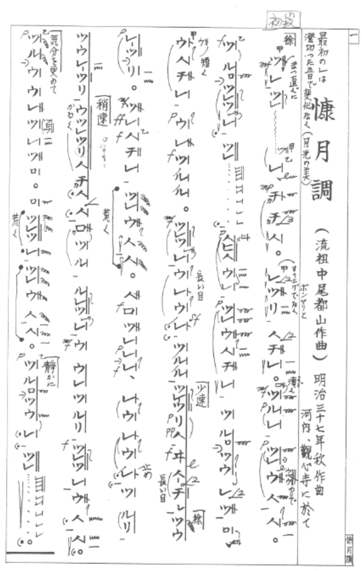
Desain, P., Honing, H., Aarts, R., and Timmers, R. (1998) Rhythmic Aspects of Vibrato. In Proceedings of the 1998 *Rhythm Perception and Production Workshop*, 34. Nijmegen.

Desain, P., Honing, H., Aarts, R., and Timmers, R. (2000) Rhythmic Aspects of Vibrato. In Desain, P. and Windsor, W. L. *Rhythm Perception and Production* Lisse: Swets & Zeitlinger

Rossignol, S., Desain, P., and Honing, H. (2001) Refined knowledge-based pitch tracking: Comparing Three Frequency Extraction Methods. *Proceedings of the International Computer Music Conference*, 399-402. San Francisco: ICMA

Rossignol, S., Desain, P., and Honing, H. (2001) State-of-the-art in fundamental frequency tracking. *Proceedings of Workshop on Current Research Directions in Computer Music*, 244-254. Barcelona: UPF.

Timmers, R., and Desain, P. (2000). Vibrato: questions and answers from musicians and science. *Proceedings of the sixth ICMPC*. Keele. CD-Rom.



Score of 'Kohgetsucho, a solo piece for Shakuhachi usedfor a vibrato study.

5.2 Methodological studies

In these studies the emergent methodology of computational modeling is made explicit. The issues addressed range from the fundamental problems of the methodology of computational modeling to detailed technical and practical solutions. The consequences of the underlying computational research formalisms and paradigms were addressed in a study on the use of physical metaphors in modeling cognition.

5.2.1 From programming language towards a cognitive modeling language

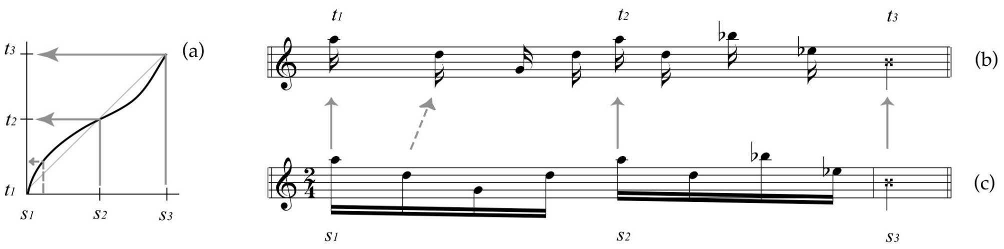
In this study we proposed to develop constructs based on the abstraction mechanisms developed in computing science (data-, procedural- and control abstractions) to be used for annotating a computer program as a computational model. Unfortunately, this project had to be discontinued because it proved impossible to find someone with the appropriate expertise to realize it. However, a start was made with two publications that explicitly addressed the advantages and disadvantages of the method of computational modeling.

Desain, P., Honing, H., Thienen, H. van, and Windsor, W. L. (1998) Computational Modeling of Music Cognition: Problem or Solution? *Music Perception* 151-166.

Desain, P., and Honing, H. (1998) A reply to S. W. Smoliar's "Modelling Musical Perception: A Critical View". N. Griffith, and P. Todd (eds.), *Musical Networks, Parallel Distributed Perception and Performance*.111-114. Cambridge: MIT Press ISBN: 0-262-07181-9.

5.2.2 Programming language design for music

This project combines a number of studies concerned with the formalization and representation of music performance and musical structure. The most important outcome of this research is that a large part of the timing patterns found in music performance can be linked directly to the musical structure, like the recurrent patterns linked to the metrical structure that are used in jazz swing or the typical slowing down at the end of phrases in classical music of the Romantic period. Furthermore, timing is adapted with regard to the global tempo: at different tempi different structural levels of the music are emphasized. The study showed how existing representations of timing as used in models of expressive timing and in computer music composition systems (such as time-maps, tempo or time-shift functions) can be extended to support both types of timing: tempo change and time shift. These so called *timing functions* form the basis of a modular and transformable representation of timing to be used in programming languages for music.
Most of this work will also find a place in a textbook on programming and modeling to be finished by Desain in 2003/2004.



Timing functions applied to a piano-piece by Colon Nancarrow.

Dannenberg, R. B., Desain, P., and Honing, H. (1997). Programming language design for music. In G. De Poli, A. Picialli, S. T. Pope, and C. Roads (eds.), *Musical Signal Processing*. 271-315. Lisse: Swets & Zeitlinger .
Desain, P. (in preparation). *Lisp as a second language: composing programs and music*. Lisse:Swets & Zeitlinger.
Desain, P., Honing, H. (1997) CLOSe to the edge? Advanced object oriented techniques in the representation of musical knowledge. *Journal of New Music Research*, 2, 1-16.
Honing, H. (2001) From time to time: the representation of timing and tempo. *Computer Music Journal*, 35(3), 50-61.
Rowe, R. (2002) *Machine Musicianship*. Cambridge: MIT press.[4]

5.2.3 Sub-symbolic vs. symbolic processing and representation

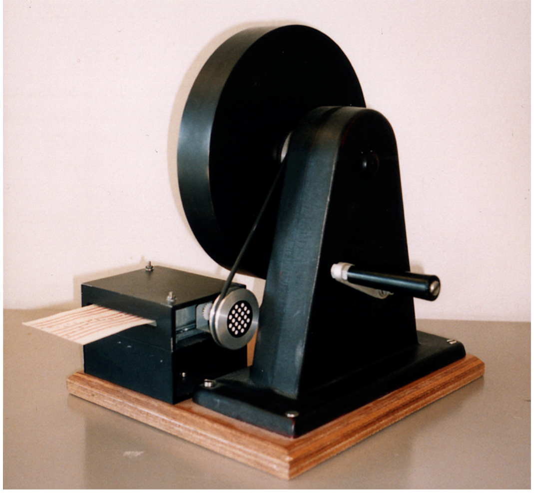
The original aim of this work was to relate two very different paradigms: the connectionist and the symbolic models of rhythm perception and production. However, it was discovered that data from perceptual studies (i.e. deriving a symbolic rhythm representation from a continuous pattern of time intervals) and from performance studies (producing a continuous pattern of time intervals from a symbolic rhythm representation) were incongruent. We focused on this puzzling asymmetry, as it seemed to pose clear counter evidence against the recent cognitive theories that assume an intimate link between processes of perception and production and their mental representations. We showed that Bayes rule can be applied to the datasets, to account for the competition between mental representations for different rhythms, a process that appears to take place only in perception. This made the counter evidence disappear. It also showed how human rhythm perception is optimally adjusted to an environment in which the various rhythms are being performed.

Desain, P., Honing, H., and Sadakata. M. (*2003*). Predicting rhythm perception from rhythm production and score counts: the Bayesian approach. *Proceedings of the SMPC 2003*, Las Vegas.
Sadakata. M., Desain, P., and Honing, H. (submitted). The relation between rhythm perception and production: towards a Bayesian model. *Psychological Review*.
Sadakata, M., Desain, P. and Honing, H (2002) The relation between rhythm perception and production: towards a Bayesian model. *Transactions of Technical Committee of Psychological and Physiological Acoustics*, Acoustical Society of Japan, 32 (10), H-2002-92.

[4] Prof. Rowe worked on this book while on sabbatical at the MMM group.

5.2.4 Physical motion as a metaphor for timing in music

In music theory, when one talks about rhythm, timing and tempo, often the analogy with physical motion is made. For example, in comparing tempi, one uses terms like walking or moving, and to characterize the progression of music (be it harmonic, melodic, rhythmic or timing wise) the notion of motion or flow is frequently used. In music psychology the physical metaphor is abundant as well, and it has inspired new theoretical results. In contrast with modern perception-action theories, this naive metaphorical link between music and motion has serious shortcomings. We suggest an alternative based on perceptual mechanisms.



Machine demonstrating a constant braking force model of the 'Final ritard'

Honing, H. (2003) The final ritard: on music, motion, and kinematic models. *Computer Music Journal*, 27(3), 66-72.

Honing, H. (2003) Some comments on the relation between music and motion. *Music Theory Online*, 9(1).

Desain, P., and Honing, H. (1996). Physical motion as a metaphor for timing in music: the final ritard. In *Proceedings of the 1996 International Computer Music Conference*. 458-460. San Francisco: ICMA.

Desain, P., and Honing, H. (1996). Mentalist and physicalist models of expressive timing. In Abstracts of the 1996 *Rhythm Perception and Production Workshop*.Munchen: Max-Planck-Institute.

5.3 New studies

This section describes some studies that were not foreseen in the original proposal.

5.3.1 ERP

Traditionally, the number of measurement devices that were used by psychologists was quite limited. Whereas nowadays, not only numbers of errors, reaction times and subjective ratings are measured, the activity of the intact brain can be directly observed while it is engaged in an experimental task.

Two directions were taken; the first was to measure the amount of surprise at a missing, but expected note, or at an unexpected probe note. The second tried to identify which rhythm a subject perceives or imagines. Some of the experiments for the latter direction still need to be reported on in articles to be written by Desain in the period 2003/2004. The success of this method, however, already led to a new STW proposal that aims at applying detection of imagined rhythms for control and communication by handicapped people.

Desain, P. and Honing, H. (submitted). Reading the musical mind. Detection of perceived and imagined rhythm from single trial ERP. *Psychological Research*.

Desain, P., Honing, H. (2003). Single trial ERP allows Detection of Perceived and Imagined Rhythm. *Proceedings of the RENCON workshop, International Joint Conference on Artificial Intelligence*.

Jenks, K.M., Jongsma, M.L.A., Desain, P., Honing, H. and Van Rijn, C.M. (2002) Omission Evoked Potentials (OEPs) in rhythmically trained and non-trained subjects. *Cognitive Neuroscience Society Ninth Annual Meeting B90*, pg 63.

Jenks, K.M., (2002) *Omission Evoked Potentials (OEPs) in rhythmically trained and non-trained subjects*. Unpublished Master Thesis, KU Nijmegen.

Jongsma, M.L.A, Coenen, A.M.L., and Van Rijn, C.M. (2002) Omission evoked potentials (OEPs) in rats and the effects of diazepam. *Psychophysiology*. 39, 1-7.

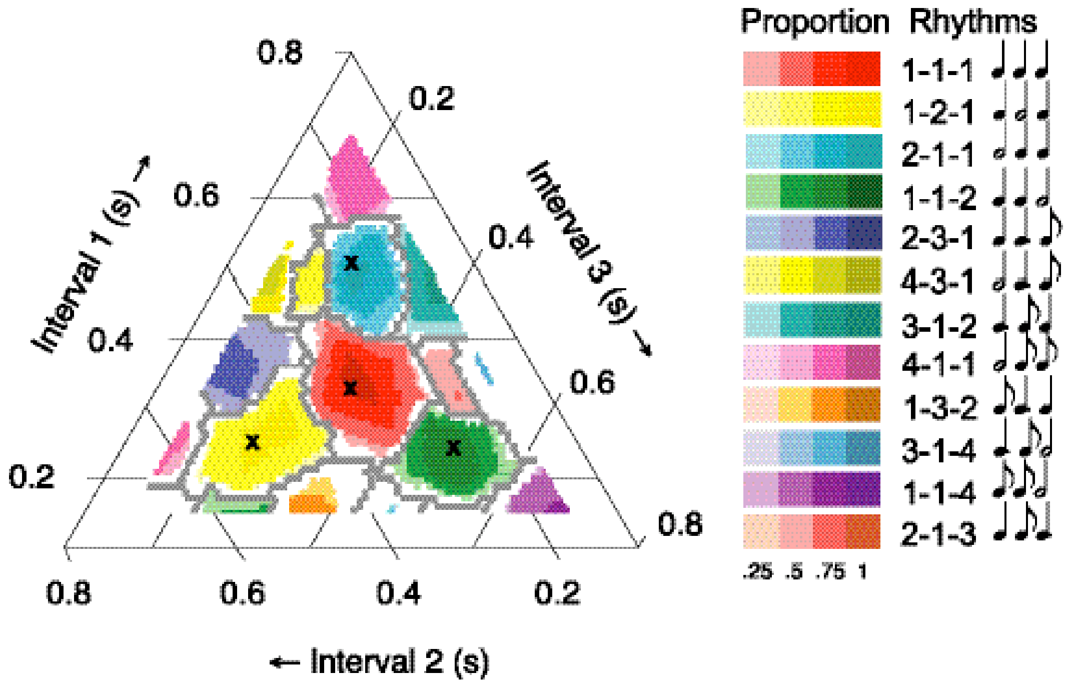
Jongsma, M.L.A., Desain, P., and Honing, H (submitted) Rhythmic context differentially influences the auditory evoked potentials of musicians and non-musicians.

Jongsma, M.L.A., Desain, P., Honing, H., Van Rijn, C.M., Jenks, K.M., and Coenen, A.M.L. (2002) AEP P300 modulation by two different temporal contexts in both rhythmically trained and non-trained subjects. *Cognitive Neuroscience Society Ninth Annual Meeting*, A94, pg 37.

Sambeth, A., Maes, J. H. R., Van Luijtelaar, G., Molenkamp, I. B. S., Jongsma, M. L. A., and Van Rijn, C. M. (In press). Auditory Event Related Potentials in humans and rats: effects of task manipulation. *Psychophysiology*.

5.3.2 Quantization of temporal patterns / Categorical rhythm perception

These studies investigate how listeners perceive discrete rhythmic categories while listening to rhythms performed on a continuous time scale. This is studied by considering the space of all temporal patterns (all possible rhythms made up of three intervals) and how they, in perception, are partitioned into categories, i.e. where the boundaries of these categories are located. In other words, the mapping from the continuous space of a series of time intervals to a discrete, symbolic domain of integer ratio sequences is characterized. The methodological framework uses concepts from mathematics and physics (e.g., convexity and entropy) that allow for precise characterizations of the empirical results.
The results show that listeners do not just perceive the time intervals between onsets of sounds as placed in a homogeneous continuum. Instead, they can reliably identify rhythmic categories, as a chronotopic *time clumping map* reveals. Furthermore it was shown that presenting patterns in the context of a meter has a large effect on rhythmic categorization: the presence of a specific musical meter primes the perception of specific rhythmic patterns.



Time clumping map*: transforming continuous time intervals (physical time) into rhythmic categories (perceived time). (see Desain & Honing, 2003).*

Aarts, R. and Jansen, C. (1999) Categorical perception of short rhythms. In *Proceedings of the 1999 SMPC*, 57. Evanston.

Cemgil A.T. and Kappen, B. (2002) Integrating Tempo Tracking and Quantization using Particle Filtering. *Proceedings of 2002 International Computer Music Conference*.147-150.[5]

Cemgil A.T. and Kappen, B. (2002) Tempo Tracking and Rhythm Quantization by Sequential Monte Carlo In: *Advances in Neural Information Processing Systems* 14, Tom Dietterich, Sue Becker and Zoubin Ghahramani (Eds.) (pp. 1361-1368), MIT Press.[5]

Cemgil A.T. and Kappen, B. (2003) Monte Carlo Methods for Tempo Tracking and Rhythm Quantization, *Journal of Artificial Intelligence Research*, 18, 45-81.[5]

Cemgil A.T., Kappen, B. Desain, P. and Honing, H. (2000) On tempo tracking: Tempogram Representation and Kalman filtering. *Proceedings of 2000 International Computer Music Conference*. Berlin: International Computer Music Association. pp. 352-355. ***[Received Distinguished paper award]***

Cemgil, T., Desain, P., and Kappen, B. (1999) Rhythm Quantization for Transcription. In *Proceedings of the AISB'99 Symposium on Musical Creativity*, 140-146.

Cemgil, T., Desain, P., and Kappen, B. (2000) Rhythm Quantization for Transcription. *Computer Music Journal*. Vol 24:2.

Cemgil, T., Kappen, B., Desain, P., and Honing, H. (2001) On tempo tracking: Tempogram Representation and Kalman filtering. *Journal of New Music Research*. 29 (4), 259-273.

Desain, P. and Honing, H. (2003) The formation of rhythmic categories and metric priming. *Perception*. 32(3), 341-365.

Desain, P. (1999) The ingredients of a stable rhythm percept: all implicit time intervals plus integer ratio bonding between them. In *Proceedings of the 1999 SMPC*, 59. Evanston.

Desain, P. , and Honing, H. (2002) Rhythmic stability as explanation of category size. Proceedings of the International Conference on Music Perception and Cognition. Sydney: UNSW. (CD-ROM).

Desain, P. and Honing, H. (2001) Modeling the Effect of Meter in Rhythmic Categorization: Preliminary Results *Journal of Music Perception and Cognition*, 7 (2), 145-156.

Desain, P. and Windsor, W. L. (Eds) (2000) *Rhythm Perception and Production* Lisse: Swets & Zeitlinger.

Desain, P., Aarts, R., Cemgil, T., Kappen, B., Thienen, H. van, and Trilsbeek, P. (1999) Robust Time-quantization for Music, from Performance to Score. In *Proceedings of the 106th Audio Engineering Society Conference* New York.

Desain, P., Jansen, C., and Honing, H. (2000) How identification of rhythmic categories depends on tempo and meter. *Proceedings of the 2000 ICMPC*. CD-Rom.

[5] Part of the STW project on Automatic Music Transcription.

Trilsbeek, P. and Thienen, H van (1999) *Quantization for Notation: methods used in commercial musical software*. Nijmegen.
Trilsbeek, P., Desain, P. and Honing, H. (submitted). How performance style is revealed by spectral analysis of expressive timing, JASA.
Trilsbeek, P., Desain, P., and Honing, H. (2001) Spectral Analysis of Timing Profiles of Piano Performances. Proceedings of the International Computer Music Conference, 286-289. San Francisco: ICMA.

5.3.3 Fingering / motor behavior

The role of the motor system in music performance is still somewhat of a mystery. It is obvious that, for beginning musicians, the body has a large influence on their performance, while for experienced performers, the influence of the body seems to be minimal. However, the ideal situation may not be that the body is merely a means for transmitting the interpretation of the performer to the instrument, but the limitations of the body-instrument interactions constitute a separate aspect of musical expression that can be recognized and appreciated. This project made a first step in this direction as it sought to understand the role of the body in music performance by experienced guitarists. The guitar was chosen because of its high demands on the motor system and the wealth of choices for the fingering of a piece of music. The same note can be played on five strings and a guitarist has a choice of the four fingers of the left hand to play it. The choice of location and the choice of finger are constrained by physical factors and musical factors, while the resulting choices influence aspects of the performance such as timbre, articulation and timing. A model was developed that predicts which fingerings guitarists might choose if they were looking for the physically easiest fingering.

Heijink, H. (2002) *Control of redundancy in Music Performance*. Unpublished PhD Thesis. KU Nijmegen.
Heijink, H. and Meulenbroek, R.G.J. (2000). A model-based study of left-hand fingering on the classical guitar. *Proceedings of the 3rd International Conference on Methods and Techniques in Behavioral Research*. Wageningen, the Netherlands: Noldus Information Technology b.v.
Heijink, H., and Meulenbroek, R.G.J. (2002). On the complexity of classical guitar playing: Functional adaptions to task constraints. *Journal of Motor Behavior*.
Parncutt, R., Sloboda, J. A., Clarke, E. F., Raekallio, M., and Desain, P. (1997) An Ergonomic Model of Keyboard Fingering for Melodic Fragments. *Music Perception* 341-381.

5.3.4 Music performance and expressive timing

The flipside of rhythmic categorization (which takes place in perception) is the adding of timing information by a performer. The range of freedom of interpretation is reflected in the common characteristics of performers (e.g. pianists' *tempo rubato)* as well as their differences. The influence of musical context on the freedom of performance of a melody was determined in an experiment that manipulated the musical setting of a melody (e.g. homophonic vs. polyphonic setting). The global tempo turned out to be another important factor. At a next-higher level, expressive consistency was shown to constrain expressive freedom, as measured by subjective ratings of esthetic quality.

Desain, P., Honing, H., and Timmers, R. (2001) Music Performance Panel: NICI/ MMM Position Statement. *Proceedings of the Workshop on Current Research Directions in Computer Music*, Barcelona:UPF

Repp, B. H., Windsor, W. L., and Desain, P. (2002) Effects of tempo on the timing of simple musical rhythms. *Music Perception*, 19(40), 565-593.

Sadakata, M., Ohgushi, K. and Desain, P. (2002) A cross-cultural comparison study of the production of simple rhythmic patterns. *Proceedings of International Conference of Auditory Display 2002* RenCon Workshop.

Sadakata, M., Ohgushi, K. and Desain, P. (in press). A Cross-cultural Comparison Study of the Production of Simple Rhythmic patterns. *Psychology of Music*.

Timmers, R. and Honing, H. (2002) Issuing an empirical musicology of performance. In Timmers, R., *Freedom and constraints in timing and ornamentation. Investigations of music performance*. (Maastricht: Shaker Publishing, 2002), 19-49.

Timmers, R. and Honing, H. (2002) On music performance, theories, measurement and diversity. In M.A. Belardinelli (ed.). *Cognitive Processing* (International Quarterly of Cognitive Sciences), 1-2, 1-19.

Timmers, R. (2001). Context-sensitive evaluation of expression. *Proceedings of the Workshop on Current Research Directions in Computer Music*, 75-78. Barcelona:UPF

Timmers, R. (2002). Context afhankelijke regels voor expressie [Context dependent rules for expression]. *Piano Bulletin*, 20(2), 50-55.

Timmers, R. (2002). *Freedom and Constraints in Timing and Ornamentation: Investigations of music performance*. Maastricht: Shaker Publishing.

Timmers, R. (2002). On the contextual appropriateness of performance rules. In *Proceedings of SRPMME Conference* "Investigating Music Performance". London, 12. ***[Received Hickman best paper award]***

Timmers, R. (2002). On the contextual appropriateness of performance rules. In Timmers, R., *Freedom and constraints in timing and ornamentation. Investigations of music performance*. Maastricht: Shaker Publishing, 85-109.

Timmers, R. (2003). On the contextual appropriateness of expression. *Music Perception*, 20 (3). 225-240.

Timmers, R. and Ashley, R. (1999) Influences of musical context and pianist stategy on the timing of a melody. In *Proceedings of the 1999 SMPC*, 82. Evanston.

Timmers, R., Ashley, R, Desain, P, and Heijink, H. (2000) The influence of musical context on tempo rubato. *Journal of New Music Research*.131-158.

5.3.5 Score-performance matching

This study dealt with the matching of musical performances to a previously known score. The design of robust score-performance matching algorithms is an important contribution to the development of tools for the analysis of music performance. Matching algorithms are necessary, for instance, to measure timing: it has to be known which performance note relates to which score note in order to extract expressive timing patterns and calculate local tempo.
Matching is therefore an essential aspect of pre-processing for expression editors that seek to manipulate expressive timing. Existing matchers that were all originally specified in different formalisms have been re-specified within the same formalism to be able to compare their behavior. A new matcher, making use of structural information in the score, bypassed some of the problems other matchers failed to solve. This new matcher has been designed and implemented in the same formalism as the existing matchers. In 2002 it was made available as part of *POCO-web* (see Section 8.3).

Desain, P., Honing, H., and Heijink, H. (1997) Robust Score-Performance Matching: Taking Advantage of Structural Information.In *Proceedings of the 1997 International Computer Music Conference*., 337-340 . San Francisco: ICMA.

Heijink, H. and Meulenbroek, R. (2000) A model-based study of left-hand fingering on the classical guitar. In *Proceedings of the 3rd International Conference on Methods and Techniques in Behavioral Research*. Wageningen, the Netherlands: Noldus Information Technology b.v.
Heijink, H., Desain, P., Honing, H., and Windsor, W. L. (2000) Make Me a Match: An Evaluation of Different Approaches to Score-Performance Matching. *Computer Music Journal*. 24(1), pp. 43-56.
Heijink, H., Windsor, W. L., and Desain, P. (2000) Data processing in music performance research: using structural information to improve score-performance matching. *Behavior Research Methods, Instruments and Computers* 546-554.

5.3.6 Formalisation and complexity

A continued motivation to introduce clean mathematical (algebraic) structures in the cognitive modeling of music cognition gave rise to work on melodic structure and rhythmic complexity. Furthermore, the algorithms we develop for score-performance matching are in an essential way equivalent to those used for coding theories of visual perception, DNA string-matching, etc. This enabled us to contribute to some domain-independent work on algorithmic complexity of these problems.

Desain, P. and Thienen, H. van. (1997) Deutsch & Feroe Formalized. In *European Mathematical Psychology Group Conference*. 18. Nijmegen.
Helm, P. van der and Desain, P. (in preparation) Regularity detection and subsequence identification in symbol sequences and in symmetry-related supersequences.
Shmulevich, I. and Povel, D. (2000) Complexity Measures of Musical Rhythms. In Desain, P. and Windsor, W. L. *Rhythm Perception and Production* Lisse: Swets & Zeitlinger
Shmulevich, I. and Povel, D. (2000) Measure of temporal complexity. *Journal of New Music Research 61-69.*

5.4 Applications

Next to basic research in music cognition we set out to apply our findings as well. To further develop prototypes and applications we acquired additional funds, including one from NWO-STW on automated music transcription and a European grant on music technology (MOSART). However, this is not the place to report on these grants. Here we restrict ourselves to POCO, a workbench combining most of the tools developed in the course of the PIONIER project, with additional support from the UCI, KU Nijmegen.

5.4.1 POCO, a workbench for research on expression in music

POCO is a collection of tools for analyzing, transforming and synthesizing musical performances. The first version dates from 1988, and since then POCO has grown tremendously and it now contains hundreds of modules. The main users of POCO are students and researchers in music cognition, for example at North Western University (Evanston, USA), and Sheffield and Leeds universities in the UK. POCO runs only on a Macintosh with Macintosh Common Lisp, but with the POCO-Web project, an important part of the software has become available to a larger group of researchers and students via a standard Web browser on any operating system. Users can upload their data and download the result. Functions of POCO that are available in this web version are for example conversion of MIDI files to text or table files, merging and concatenation of musical data, filtering of musical data, several score-performance matching algorithms, timing and tempo analysis and several more. The software can be accessed on www.nici.kun.nl/mmm under the heading 'POCO-web' (see also Section 8.3).

Honing, H. (1998) *Vergelijking Midi-files. Deskundige Rapport*, Utrecht Court. [Expert report for Utrecht Court on comparison MIDI-files]

5.5 Collaborations

5.5.1 Data-oriented processing techniques (DOP) and meter induction

With Rens Bod and Menno van Zaanen (ILLC)
A collaboration was started on the use of data-oriented processing techniques (DOP) and the modeling of meter induction on the basis of large corpora of musical scores. Henkjan Honing joined the 'Cognitive systems and information processing' (CSIP) programme of the ILLC to further elaborate the computational modeling aspects of his research.

Zaanen, M., Bod, R. and Honing, H. (2003) A memory-based approach to meter induction. *Proceedings of the ESCOM*.

5.5.2 Dependencies of musical scores and performances on mother tongue timing

With Ani Patel of the Neuroscience Institute (San Diego) and Prof. Kengo Ohgushi of Kyoto City University of the Arts
A collaboration has recently been initiated on relating statistical regularities in musical scores to characteristics of mother tongue timing. We will investigate whether the effect that has been pinpointed for French and English does also occur in Japanese (mora-timed, as opposed to syllable- or stress-timed). This may be a reason for the cultural differences that were found in expressive timing in music performance.

Sadakata, M., Ohgushi, K. and Desain, P. (in press). A Cross-cultural Comparison Study of the Production of Simple Rhythmic patterns. *Psychology of Music*.
Sadakata, M., Desain, P., Honing, H., Ohgushi, K. and Patel, A. (in preparation). Rhythm in Japanese Language and Music.

5.5.3 Detection of imagined temporal stimuli from single-trial ERP

With Prof. Patrick Suppes of CSLI Stanford
The group of prof Suppes pursues the same aim as we in identifying patterns from ERP; his group works on language and speech, whereas we focus on rhythm. We have exchanged methods and results and will start to collaborate more closely during a planned sabbatical of Peter Desain at Stanford (2003/2004)

5.5.4 Computable minimal encoding by hyperstrings

With Peter van der Helm of NICI

Formal languages for coding regularity and structure need to be defined with concern for psychological plausibility in mind, which includes the computational feasibility of the parsing process. The visual perception group works on a rigorous foundation of the SIT language for coding regularity in visual form (e.g. symmetry and repetition). Our algorithm for symmetry coding shows a remarkable resemblance to the algorithm of string matching and can, for instance, also be applied to DNA/RNA string matching. This triggered the collaboration because of our algorithmic work on the problem of matching the notes in a performance to the notes in a score.

Helm, P. van der and Desain, P. (in preparation) Regularity detection and subsequence identification in symbol sequences and in symmetry-related supersequences.

5.5.5 The effect of anxiety on paralinguistic aspects of speech

With Muriel Hagenaars and Agnes van Minnen, dept of Clinical Psychology/KU Nijmegen

In an experimental study, paralinguistic aspects of speech are studied using autobiographical memories of patients with panic disorder. The hypothesis that significant differences in paralinguistic aspects of speech will be found between autobiographical memories with and without anxiety was confirmed, which led to the conclusion that paralinguistic speech aspects are an important part of the fear memory structure. In addition, the paralinguistic aspects of speech are evaluated for their validity as a treatment outcome measure. The MMM group contributed the audio analyses and psycho-acoustic expertise for these studies.

Hagenaars, M., Van Minnen, A., and Desain, P. (2002). Paralinguistic aspects of speech as outcome measure in prolonged exposure therapy for PTSD. Proceedings of the 32nd congress of the European Association of Behavioural and Cognitive Therapy (EABCT). Maastricht, Netherlands.

5.5.6 Decomposition of expressive timing in structurally linked layered segments

With Luke Windsor, Music Department/University of Leeds

The past twenty years have seen increasing moves toward the use of quantitative methods in musical research, especially in the domain that has become variously known as 'music psychology', 'psychology of music', 'music cognition', 'music perception' or even 'psychomusicology'. Researchers working in both musicological and psychological contexts have been drawn towards collecting empirical data from performers and listeners, and analyzing such data using statistical methods. In collaboration with the MMM group new analytical methods are being developed to be used for the analysis and decomposition of expressive timing in terms of different types of temporal structure in music. This project will be completed during Windsor's planned work visit early in 2004.

5.5.7 Applying EEG and Evoked Potential measurements to study cognitive processing of temporal patterns.

With Tineke van Rijn, Ton Coenen, Biological Psychology/KU Nijmegen
There are several theories concerning the processing of temporal information: the statistical, the pattern-based, the dynamic attending and the distributed expectancy theory. The latter theory directly predicts the amount of expectancy of each new stimulus onset within a temporal pattern. It therefore provides an ideal framework to explore the neural substrate involved in the cognitive processing of temporal information. Investigating both the P300 and the Omission Evoked Potential in response to rhythmical stimulation lead to new insights in the domain of temporal information processing. Articles are listed under section 5.3.1.

6 Scientific output and related activities

6.1 PhD projects

Renee Timmers received her PhD degree in September 2002 for her thesis "*Freedom and constraints in timing and ornamentation. Investigations of music performance*". It deals with the perception and production of expression in musical performances. The promotor was Prof. Dr. Ch. de Weert, co-promotors were Dr. P. Desain and Dr. H. Honing, and the manuscript committee consisted of Prof. Dr. J.A. Michon, Prof. Dr. R. de Groot and Prof. Dr. E. Clarke.

Hank Heijink received his PhD degree in September 2002 for his thesis "*Redundancy Control in Music Performance: Towards an Understanding of the Role of Constraint Satisfaction.*" It investigates the interaction of timing constraints and bio-mechanical constraints in music performance and the benefits of knowledge about timing constraints in musical performance for score-performance matching algorithms. Promotor was Prof. Dr. G. van Galen, co-promotors were Dr. R. Meulenbroek and Dr. H. Honing. The manuscript committee consisted of Prof. Dr. J.A. Michon, Dr. D.J. Povel and Prof. Dr. W. Schwarz.

Rinus Aarts choose in 1999 to accept a job in the ICT industry and to terminate his PhD work.

Taylan Cemgil (MBFYS) will defend his PhD thesis about modern stochastic methods for quantization and tempo tracking in the autumn of 2003. This project, funded by STW, is supervised by Dr B. Kappen from Medical Physics.

Makiko Sadakata started in 2002 as a junior researcher, working on a PhD with the provisional title "*What Perception of Time Reveals About Action in Time: Rhythmic Categories as Constraints on Expressive Freedom*". We have been able only to fund the first 3 years of this project from the PIONIER grant.

6.2 Publications

6.2.1 Refereed journals

Cemgil, T., Desain, P., and Kappen, B. (2000) Rhythm Quantization for Transcription. *Computer Music Journal*. Vol 24:2.

Cemgil, T., Kappen, B., Desain, P., and Honing, H. (2001) On tempo tracking: Tempogram Representation and Kalman filtering. *Journal of New Music Research*. 29 (4), 259-273.

Cemgil A.T. and Kappen, B. (2003) Monte Carlo Methods for Tempo Tracking and Rhythm Quantization, *Journal of Artificial Intelligence Research*, 18, 45-81.[6]

Desain, P. and Honing, H. (2003) The formation of rhythmic categories and metric priming. *Perception*. 32(3), 341-365.

Desain, P. (1998) Computationeel modelleren van muziekcognitie: waar is de tel?. *Facta* 20-22. ISSN: 0928-5350.

Desain, P. (1999) Vibrato and portamento, hypotheses and tests. *Acustica* 348. ISSN: 1436-7947.

Desain, P. and Honing, H. (1997) Computationeel modelleren van beat-inductie. *Informatie* 48-53. ISSN: 0019-9907.

Desain, P. and Honing, H. (1999) Computational Models of Beat Induction: The Rule-Based Approach. *Journal of New Music Research* ISSN: 0929-8215.

Desain, P. and Honing, H. (2000) Modeling vibrato and portamento in music performance. *Bulletin of the Council for Research in Music Education*.

Desain, P. and Honing, H. (2001) Modeling the Effect of Meter in Rhythmic Categorization: Preliminary Results *Journal of Music Perception and Cognition*, 7 (2), 145-156.

Desain, P., Honing, H. (1997) CLOSe to the edge? Advanced object oriented techniques in the representation of musical knowledge. *Journal of New Music Research*, 2, 1-16. ISSN: 0929-8215.

Desain, P., Honing, H., Thienen, H. van, and Windsor, W. L. (1998) Computational Modeling of Music Cognition: Problem or Solution?.*Music Perception* 151-166.

Heijink, H., and Meulenbroek, R.G.J. (2002). On the complexity of classical guitar playing: Functional adaptions to task constraints. *Journal of Motor Behavior*.

Heijink, H., Desain, P., Honing, H., and Windsor, W. L. (2000) Make Me a Match: An Evaluation of Different Approaches to Score-Performance Matching. *Computer Music Journal*. 24(1), pp. 43-56.

Heijink, H., Windsor, W. L., and Desain, P. (2000) Data processing in music performance research: using structural information to improve score-performance matching. *Behavior Research Methods, Instruments and Computers* 546-554.

Honing, H. (2001) From time to time: the representation of timing and tempo. *Computer Music Journal*, 35(3), 50-61.

Honing, H. (2003) Some comments on the relation between music and motion *Music Theory Online*, 9(1).

Honing, H. (2003) The final ritard: on music, motion, and kinematic models. *Computer Music Journal*, 27(3).

Jongsma, M.L.A, Coenen, A.M.L., and Van Rijn, C.M. (2002) Omission evoked potentials (OEPs) in rats and the effects of diazepam. *Psychophysiology*. 39, 1-7.

Jongsma, M.L.A., Desain, P., and Honing, H (submitted) Rhythmic context differentially influences the auditory evoked potentials of musicians and non-musicians.

Karakurum, E, Bouwman, B.M., Patsalos, P.N., Jongsma, M.L.A., Van den Broek, P.L.C., Coenen, A.M.L., Van Rijn, C.M. (In press). The anti epileptic vigabatrin induces in the EEG of rats behaviour-independent increase of delta - and decrease of beta power. *Sleep-Wake Research in the Netherlands* 12, 54-57.

Parncutt, R., Sloboda, J. A., Clarke, E. F., Raekallio, M., and Desain, P. (1997) An Ergonomic Model of Keyboard Fingering for Melodic Fragments. *Music Perception* 341-381. ISSN: 0730-7829.

Repp, B. H., Windsor, W. L., and Desain, P. (2002) Effects of tempo on the timing of simple musical rhythms. *Music Perception*, 19(40), 565-593.

Sadakata, M., Desain, P. and Honing, H (2002) The relation between rhythm perception and production: towards a Bayesian model. *Transaction of Technical Committee of Psychological and Physiological Acoustics*, Acoustical Society of Japan, 32 (10), H-2002-92.

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Shmulevich, I. and Povel, D. (2000) Measure of temporal complexity. *Journal of New Music Research* 61-69.

[6] Part of the STW project on Automatic Music Transcription.

Timmers, R. and Honing, H. (2002) On music performance, theories, measurement and diversity. In M.A. Belardinelli (ed.). *Cognitive Processing* (International Quarterly of Cognitive Sciences), 1-2, 1-19.

Timmers, R. (2002). Context afhankelijke regels voor expressie [Context dependent rules for expression]. *Piano Bulletin*, 20(2), 50-55.

Timmers, R. (2003). On the contextual appropriateness of expression. *Music Perception*, 20 (3). 225-240.

Timmers, R., Ashley, R, Desain, P, and Heijink, H. (2000) The influence of musical context on tempo rubato. *Journal of New Music Research*.131-158.

Timmers, R., Ashley, R., Desain, P., Honing, H., and Windsor, L. (2002) Timing of ornaments in the theme of Beethoven's Paisiello Variations: Empirical Data and a Model. *Music Perception*, 20(1), 3-33.

Windsor, W. L., Aarts, R., Desain, P., Heijink, H., and Timmers, R. (2001) The timing of grace notes in skilled musical performance at different tempi: a preliminary case study. *Psychology of Music*, 29, 149-169.

Desain, P., Honing, H. (submitted). Reading the musical mind. Detection of perceived and imagined rhythm from single trial ERP. *Psychological Research*.

Sadakata. M., Desain, P., and Honing, H. (submitted). The relation between rhythm perception and production: towards a Bayesian model. *Psychological Review*.

Trilsbeek, P., Desain, P. and Honing, H. (submitted). How performance style is revealed by spectral analysis of expressive timing, *JASA*.

6.2.2 Books, or contribution to books

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Dannenberg, R. B., Desain, P., and Honing, H. (1997). Programming language design for music. In G. De Poli, A. Picialli, S. T. Pope, and C. Roads (eds.), *Musical Signal Processing*. 271-315. Lisse: Swets & Zeitlinger ISBN: 90-265-1483-2.

Desain, P. and Windsor, W. L. (Eds) (2000) *Rhythm Perception and Production* Lisse: Swets & Zeitlinger.

Desain, P., and Honing, H. (1998) A reply to S. W. Smoliar's "Modelling Musical Perception: A Critical View". N. Griffith, and P. Todd (eds.), *Musical Networks, Parallel Distributed Perception and Performance*.111-114. Cambridge: MIT Press ISBN: 0-262-07181-9.

Desain, P., Honing, H., Aarts, R., and Timmers, R. (2000) Rhythmic Aspects of Vibrato. In Desain, P. and Windsor, W. L. *Rhythm Perception and Production* Lisse: Swets & Zeitlinger.

Rowe, R. (2002) *Machine Musicianship*. Cambridge: MIT press.

Shmulevich, I. and Povel, D. (2000) Complexity Measures of Musical Rhythms. In Desain, P. and Windsor, W. L. *Rhythm Perception and Production* Lisse: Swets & Zeitlinger

Timmers, R. and Honing, H. (2002) Issuing an empirical musicology of performance. In Timmers, R., *Freedom and constraints in timing and ornamentation. Investigations of music performance*. (Maastricht: Shaker Publishing, 2002), 19-49.

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6.2.3 Refereed conference proceedings

Aarts, R. and Jansen, C. (1999) Categorical perception of short rhythms. In *Proceedings of the 1999 SMPC*, 57. Evanston.

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Cemgil A.T., Kappen, B. Desain, P. and Honing, H. (2000) On tempo tracking: Tempogram Representation and Kalman filtering. *Proceedings of 2000 International Computer Music Conference*. Berlin: International Computer Music Association. pp. 352-355. ***[Received Distinguished paper award]***

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Desain, P., Honing, H., and Timmers, R. (2001) Music Performance Panel: NICI/ MMM Position Statement. *Proceedings of the Workshop on Current Research Directions in Computer Music*, Barcelona:UPF
Desain, P., Honing, H., and Heijink, H. (1997) Robust Score-Performance Matching: Taking Advantage of Structural Information.In *Proceedings of the 1997 International Computer Music Conference*., 337-340 . San Francisco: ICMA.
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Penel, A., Desain, P., Maris, E., and Windsor, W. L. (1999) A decomposition model of expressive timing. In *Proceedings of the 1999 SMPC*, 21. Evanston.
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Timmers, R., Desain, P., and Honing, H. (2000). Timing of grace notes in piano performances of a Beethoven Theme. *Proceedings of the eighth International Workshop on Rhythm Perception and Production*. Castleton.
Timmers, R., Desain, P., Honing, H., and Trilsbeek, P. (2002). Introducing a model of grace note timing. In *Proceedings of the Workshop on Music, Motor Behavior and the Mind*. Ascona, 32.
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Zaanen, M., Bod, R. and Honing, H. (2003) A memory-based approach to meter induction. *Proceedings of the ESCOM*.

6.2.4 Other

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Jenks, K.M., *Omission Evoked Potentials (OEPs) in rhythmically trained and non-trained subjects*. Unpublished Master Thesis, KU Nijmegen.
Trilsbeek, P. and Thienen, H van (1999) Quantization for Notation: methods used in commercial musical software. Nijmegen.
Penel A. (2000) Variations Temporelles dans l'Interpretation Musicale: Processus Perceptifs et Cognitifs. Unpublished PhD Thesis. Université Paris V.[7]

6.3 Presentations

6.3.1 Internal Lab meetings

Next to presentations on ongoing research by team members, many other researchers in music cognition presented their work at the MMM lab meetings, usually as a one hour long lecture. We give here a selection:

- Rene van Egmond (NICI). *A tonality recognition model*
- Piet Vos (NICI). *Musical openings: modelling and data*
- Michael Brady (Ohio State University). *Adaptive Beat Tracker, an oscillator-based "foot tapper"*
- Edward W. Large (University of Pennsylvania). *Simulating meter perception from digital audio*
- Mireille Besson, (CRNC Marseille). *ERP measurements in music perception*
- Pau Bofill (UPC Barcelona) *Auditory Analysis*
- Taylan Cemgil (NICI) *Quantization*
- Amandine Penel (CNRS Paris) *Sources of timing variations in music performance*
- Nico Schuller (Michigan State University) *Computer assisted music analysis*
- Joost van der Weijer (Max Planck Instituut). *Language input for word discovery*
- Bruno Repp (Haskins Laboratory). *Individual Differences in Shaping a Musical Phrase: The Opening of Chopin's Etude in E Major*
- Robert Rowe (New York University) *Machine Musicianship*
- Wout Croonen (formerly: University of Eindhoven) *Herkenning van toonreeksen: invloeden van reekslengte, tonale sterkte en contour.*
- John Puterbaugh (Voxware Inc.). *Auditory models and sinusoidal analysis/synthesis system*
- Dan Gang (Hebrew University Jerusalem). *A Computational Model of Meter*

[7] The research for one chapter of this thesis was conducted while A. Penel visited the MMM group.

Cognition During the Audition of Functional Tonal Music: Modeling A-priori Bias in Meter Cognition.
- Robert Rowe (New York University) *Machine Musicianship*
- Christopher Yavelow (freelance researcher) *Generation of musical compositions*
- Barbara Tillman (Universite de Bourgogne) *Connectionist Simulations of Perceptual Learning in Tonal Music*
- Anneke Neijt (Katholieke Universiteit Nijmegen) *Ritme in taal*
- Leigh Smith (University of Western Australia) *Foot-tapping by Time-Frequency Reconstruction*
- Marcelo Wanderly. IRCAM, Paris, France. *Expressive Movements in Clarinet Performance*
- Shula Brouwer, UvA. *Tempo and Timing*
- Justin London, Carleton College, Northfield, USA. *Perception and Cognition of Meter*
- Titia van Zuijen, University of Helsinki. *Neural encoding of consecutive sounds*
- Stéphane Rossignol, IRCAM, Paris, France. *Segmentation of Auditory Signals.*
- Belinda Thom, Carnegy Mellon University, Pittsburgh. *Interactive Music Systems*
- Marcelo Wanderly, IRCAM, Paris, France. *Research on expressive movements in clarinet performance.*
- Justin London, Carleton College, Northfield, USA. *Metrical structure*
- Kengo Ohgushi, Kyoto City University of the Arts, Kyoto, Japan.
- Makiko Sadakata, Kyoto City University of the Arts, Kyoto, Japan.
- Yoshitaka Nakajima, Kyushu Institute Of Design, Fukuoka, Japan
- Gert ten Hoopen, University of Leiden, Faculty Of Social And Behavioral Sciences, The Netherlands
- Dough Eck, Indiana University, Cognitive Science Program, Bloomington, USA
- Edwin de Jong, Computer Science Department, Brandeis University, USA.

6.3.2 Internal tutorials, training and workshops

During the years several tutorials were given in the studio, to share and develop knowledge about the methodology and contents of the field and the tools used. This was especially essential during the first years, due to the multi-disciplinary nature of the project and its researchers. Where necessary, tutorials and workshops have been extended to last for up to a week. Sometimes these tutorials were led by members of the group, but often external experts were invited. It proved very productive to explicitly allocate time to the development of effective collaboration and communication skills in the form of these workshops.

- Collaboration training (Jacqueline van der Pol)
- Communication and collaboration (Eva Wiltingh)
- Communication and collaboration (Jacqueline van der Pol)
- Computability and Formal Languages (Ilya Shmulevich)
- Design and operation of the Studio (Peter Desain and Rinus Aarts)
- Ecological psychology (Chris Jansen)
- Empirical Studies of Expressive Timing (Luke Windsor)
- Expression and Structure in Music (Caroline Palmer)
- Expressive Timing in Jazz Performance (Ric Ashley)
- Finale (Hank Heijink)
- Generative Theory of Tonal Music (Luke Windsor and Renee Timmers)
- HTML (Rinus Aarts and Huub van Thienen)
- HTML web programming (Peter Desain and Huub van Thienen)
- Illustrator (Henkjan Honing)
- Interview Techniques (Thea van Lankveld)
- JMP (Rinus Aarts)

- LISP programming (Henkjan Honing)
- LISP programming (Huub van Thienen)
- Macintosh Maintenance (Paul Trilsbeek)
- Matlab (Peter Snoeren)
- Music Technology (Daphne Naftali)
- Now Up To Date (Paul Trilsbeek)
- NowContact address database (Paul Trilsbeek)
- Operation of Yamaha O3D Digital Mixer (Rinus Aarts)
- Oral presentation training (Esther Hinne)
- OSX (Paul Trilsbeek)
- POCO use (Peter Desain)
- Presentation Skills (Esther Hinne)
- ProCite Tutorial (Peter Desain)
- Programming in Lisp (Henkjan Honing)
- Rhythmic Structure of Music (Renee Timmers)
- Spectral Analysis (Ilya Shmulevich)
- Studio Peripherals (Rinus Aarts and Paul Trilsbeek)
- Team building (Eva Wiltingh)
- Vision and research directions (Jacqueline van der Pol)

6.3.3 External Presentations

Structural Expression Component Theory (SECT)
Peter Desain, Henkjan Honing
Conference of the Society for Music Perception and Cognition
Cambridge, USA, 1997

POCO software environment
Peter Desain, Henkjan Honing
International Congress of the International Musicological Society, London, UK, 1997

How to evaluate generative models of expression in music performance
Peter Desain, Henkjan Honing
International Joint Conference on Artificial Intelligence
Nagano Japan, 1997

Deutch and Feroe formalized
Peter Desain, Huub vanThienen
European Mathematical Psychology Group Conference, Nijmegen, The Netherlands. 1997

Complexity Measures of Musical Rhythms
Ilya Shmulevich
IEEE Workshop on Applications of Signal Processing to Audio and Acoustics
New Paltz, USA, 1997

Robust Score-Performance Matching
Peter Desain, Hank Heijink, Henkjan Honing
International Computer Music Conference, Tessaloniki, Greece, 1997

Computational modeling of rhythm perception
Peter Desain, Henkjan Honing
Workshop on Language and Music Processing, Marseille, France, 1997

Vibrato
Henkjan Honing
Seashore Symposium, Iowa, USA, 1997

Modeling vibrato and portamento in music performance
Peter Desain and Henkjan Honing
Coloquium vakgroep Fysica van de Mens
Buys Ballot Laboratorium, RUU, 1998

Rhythm Complexity Measures for Music Pattern Recognition
Ilya Shmulevich, Dirk Povel
IEEE Workshop on Multimedia Signal Processing, Redondo Beach, California, 1998

Rhythmic aspects of vibrato
Rinus Aarts and Renee Timmers
Rhythm Production and Perception Workshop, NIAS, Wassenaar, 1998

Complexity measures of musical rhythms
Ilya Shmulevich and Dirk-Jan Povel
Rhythm Production and Perception Workshop, NIAS, Wassenaar, 1998

Graceful timing, ornaments, tempo and musical structure
Luke Windsor
Rhythm Production and Perception Workshop, NIAS, Wassenaar, 1998

Music Mind Machine project
Rinus Aarts and Peter Desain
Avontuur op de campus, KU Nijmegen, 1998

Het mysterie van vibrato
Peter Desain
Studium Generale, KU Nijmegen, 1998

Analyzing vibrato in music performances; method and result
Renee Timmers
Perception Meeting, NICI, KU Nijmegen, 1998

Analyzing vibrato in music performances; method and result
Renee Timmers
Internationaler Kongress der Gesellschaft fur Musikforschung
Martin-Luther-Universität Halle-Wittenberg, Germany, 1998

Presentation and Demonstration MMM en Vibrato
Huub Thienen and Renee Timmers
Reunion ex-Psychology students and co-workers, KU Nijmegen, 1998

Vibrato,
Huub van Thienen
NICI Aio/oio dag Poster presentations, KU Nijmegen, 1998

Quantization,
Paul Trilsbeek
NICI Aio/oio dag Poster presentations, KU Nijmegen, 1998

Grace notes
Rinus Aarts
NICI Aio/oio dag Poster presentations, KU Nijmegen, 1998

Modeling vibrato and portamento in music performance
Peter Desain and Henkjan Honing
Colloquium vakgroep Fysica van de Mens
Buys Ballot Laboratorium, RUU, 1999

Robust Time-quantization for Music, from Performance to Score
Peter Desain
106th AES convention
Munich, Germany, 1999

Good vibrations, structuur en regelmaat in musikaal vibrato
Peter Desain and Renee Timmers
OKW L. van der Poll Stichting Lezingencyclus Hersenen en bewustzijn.
Paradiso, Amsterdam, 1999

Good vibrations, structuur en regelmaat in musikaal vibrato
Peter Desain and Renee Timmers
Colloqium serie Mbfys
Sichting Neurale Netwerken, Nijmegen, 1999

Vibrato and Portamento
Peter Desain
Meeting of the Acoustical Society of America
TU Berlin, Germany, 1999

The ingredients of a stable rhythm percept
Peter Desain
SMPC
NWU, Evanston, USA, 1999

Tonality perception in musical excerpts and chords
Rene van Egmond
SMPC
NWU, Evanston, 1999

Take it Easy: a Model of Left-hand Fingering on the Classical Guitar
HankHeijink
SMPC
NWU, Evanston, USA, 1999

An Evaluation of Different Approaches to Score-Performance Matching
Hank Heijink
Computer Music Lab
Carnegie-Mellon University, USA, 1999

Take it Easy: a Model of Left-hand Fingering on the Classical Guitar
Hank Heijink
Computer Music Lab
Carnegie-Mellon University, USA, 1999

Categorical perception of short rhythms
Chris Jansen
SMPC
NWU, Evanston, USA, 1999

Quantization and expressive timing
Chris Jansen and Renee Timmers
Introductie in de muziekpsychologie
KU Nijmegen, Nijmegen

Quantization and expressive timing
Chris Jansen and Renee Timmers
Voorlichtingsdag 4 VWO
KU Nijmegen, Nijmegen, 1999

Influences of musical context and pianist strategy on the timing of a melody
Renee Timmers
SMPC
NWU, Evanston, USA, 1999

Barriers on the Road Toward a Theory of Music
Dirk-Jan Povel
Workshop MusicCog Ohio State University, 1999.

Determinants of Melodic Goodness.
Dirk-Jan Povel
Workshop MusicCog Ohio State University, 1999.

First Steps in Simulating Music processing
Dirk-Jan Povel
School of Music, Northwestern University,1999.

Mechanisms in the perception of accented melodic sequences
Erik Jansen and Dirk-Jan Povel
SPMC
NWU Evanston, 1999

De rol van impliciete harmonieën in de waarneming van muziek
Erik Jansen and Dirk-Jan Povel
7th Dutch Psychonomics Conference, Egmond aan Zee, 1999.

Quantisatie van Temporele Patronen voor Automatische Muziektranscriptie
Peter Desain and Henkjan Honing,
STW Bestuursvergadering, Utrecht, 2000

Vibrato: Questions and answers of science and musicians.
Renee Timmers and Peter Desain.
ICMPC, Keele, England, 2000

How identification of rhythmic categories depends on tempo and meter.
Peter Desain, Chris Jansen and Henkjan Honing
ICMPC, Keele, England, 2000

The timing of grace notes in piano performances of a Beethoven Theme.
Renee Timmers, Peter Desain and Henkjan Honing.
RPPW, England, 2000

Ritme perceptie onderzoek binnen MMM
Peter Desain and Henkjan Honing
VSNU beleidsgroep, KU Nijmegen, 2000

Expressie in muziek
Peter Desain
Muziektechnologie opleiding, HKU, Hilversum, 2000

Research in the Music, Mind, Machine group
Henkjan Honing
DIKU, Copenhagen, Denemarken. 2000

Vibrato and Movement.
Erwin Schoonderwalt
DIKU, Copenhagen, Denemarken. 2000

Over ritme en klonters in de tijdpap.
Peter Desain and Henkjan Honing.
NWO Bessensap Lustrumfeest over Wetenschap en Journalistiek. Felix Meritis, 2000
Amsterdam.

Amazing grace: timing of a musical ornament.
Renee Timmers.
Poster presentation at the NICI AIO/OIO day.
Nijmegen, 2000

Modeling rhythm perception and quantization
Peter Desain and Henkjan Honing
invited lecture, University Pompeu Fabra, Barcelona, Spain, 2001

Music and Logic
Henkjan Honing
Symposium Music and Logic, Gent, Belgium, 2001

Tutorial on rhythm perception
Henkjan Honing
MOSART Meeting in Padova, Italy, University of Padoa, Italy, 2001

Quantisatie van temporele patronen
Henkjan Honing
STW/Congresgebouw Den Haag, The Netherlands, 2001

MMM Position Statement
Henkjan Honing
music performance panel, panel member. UPF, Barcelona, Spain, 2001

Current directions in computer music research
Henkjan Honing
MOSART Meeting, Barcelona, Spain, 2001

Over het klonteren van de tijd: Categorieën en ritmeperceptie
Peter Desain and Henkjan Honing
Colloquium muziekwetenschap, UvA, Amsterdam, 2001

Over het klonteren van de tijd: Categorieën en ritmeperceptie
Peter Desain and Henkjan Honing
Wintercongres NVP, Egmond aan Zee, The Netherlands, 2001

The effect of Diazepam on EEG-AEP interralations in rats
Marijtje Jongsma
XV International Congress of Clinical Neurophysiology, Buenos Aires, Argentinië, 2001

Omission evoked potentials (OEPS) in rhythmically trained and non-trained subjects
Marijtje Jongsma
Wintercongres NVP, Egmond aan Zee, The Netherlands, 2001

Introduction á la Psychoacoustique
Stéphane Rossignol
Course on psycho-acoustics, BEIAP, Metz, France, 2001

Vibrato modeling: Refined knowledge-based pitch-tracking for vibrato analysis
Stéphane Rossignol
MOSART Meeting, Padova, Italy, 2001

Refined Knowledge-Based f0 Tracking
Stéphane Rossignol
ICMC Havana, Cuba, 2001

State-of-the-art in fundamental frequency tracking
Stéphane Rossignol
MOSART Meeting, Barcelona, Spain, 2001

Grace note timing: Stealing, shifting and (non-) scaling
Renee Timmers
Northwestern University, Illinois, USA, 2001

Stolen times and inflexible duration in the timing of ornaments
Renee Timmers
SMPC, Kingston, Canada, 2001

Context-sensitive evaluation of expression
Renee Timmers
MOSART Meeting, Barcelona, Spain, 2001

Spectral analysis of timing profiles of piano performances
Paul Trilsbeek
ICMC, Havana, Cuba, 2001

Regels voor de uitvoering van muziek; contextualiteit en muzikale structuur
Renee Timmers
Colloquium Psychologie, Universiteit Leiden, NL (invited lecture), 2002

On the contextual appropriateness of performance rules
Renee Timmers
SRPMME conference. London, UK (invited lecture), 2002

AEP P300 modulation by two different temporal contexts
Marijtje Jongsma
Cognitive Neuroscience Society Ninth Annual Meeting, San Francisco, 2002

Modeling rhythm perception and quantization
Peter Desain and Henkjan Honing
University Pompeu Fabra, Barcelona, Spain (invited lecture), 2002

Introducing a model of grace note timing
Renee Timmers
Workshop on Music, Motor Behavior and the Mind. Ascona. Switserland, 2002

Rhythmic categories and expressive timing
Peter Desain
Music Performance Symposium, Stockholm, Sweden (invited lecture), 2002

A cross-cultural comparison study of the production of simple rhythmic patterns
Makiko Sadakata
RenCon, Nara, Japan, 2002

Detection of rhythmic patterns from ERP
Peter Desain
Tohoku University Sendai, Japan (invited lecture), 2002

Stability as explanation of rhythmic category size
Peter Desain and Henkjan Honing
ICMPC Sydney, Australia, 2002

Research on grace notes timing and timing of melodies
Renee Timmers
MOSART Midterm Meeting, Esbjerg, Denmark2, 002

ERP and rhythm
Peter Desain
SCCD, UCSD, La Jolla, USA (invited lecture), 2002

ERP and rhythm
Peter Desain
NeuroScience Institute , La Jolla, USA (invited lecture), 2002

Rhythmic Categories
Peter Desain
CCRMA Stanford University, USA (invited lecture), 2002

ERP and rhythm
Peter Desain
CSLI Stanford University, USA (invited lecture), 2002

Omission Evoked Potentials (OEPs) in rhythmically trained and non-trained subjects
Marijtje Jongsma
The Neurosciences and Music, Venice, Italy (poster presentation), 2002

Detection of perceived and imagined rhythm from ERP, a method for
reading the musical mind
Peter Desain
The Neurosciences and Music, Venice, Italy (poster presentation), 2002

Ritmische Categorieën
Peter Desain and Henkjan Honing
NWO-Cognitie startdag, Nemo, Amsterdam, NL (demonstration), 2002

Modeling rhythm perception and quantization.
Henkjan Honing
Music and AI Group, University of Edinburgh, UK (invited lecture), 2002

Rhythm and timing: a cognitive approach
Henkjan Honing
Music Cognition Series. New York University, USA (invited lecture), 2002

Rhythm and timing: a cognitive approach
Henkjan Honing
Ohio State University, School of Music, Columbus, USA (invited lecture), 2003

Rhythm and timing: a cognitive approach
Henkjan Honing
McGill University, Department of Psychology, Montreal, CA (invited lecture), 2003

Music technology and the role of music cognition research
Henkjan Honing
Media Studies, University of Amsterdam, NL (invited lecture), 2003

Rhythm perception and categorization
Henkjan Honing
School of Informatics, City University, London, UK (invited lecture), 2003

Structure and interpretation of rhythm and timing
Henkjan Honing
Music and Arts Professions Department, New York University, USA(invited lecture), 2003

Rhythm perception and categorization
Henkjan Honing
Institute for Research in Cognitive Science (IRCS), UPENN, USA(invited lecture), 2003

Predicting rhythm perception from production using a Bayesian approach
Peter Desain, Henkjan Honing & Makiko Sadakata
Society for Music perception and Cognition
Las Vegas, USA, 2003

Reading the musical mind, identification of perceived and imagined temporal patterns in ERP
Peter Desain & Henkjan Honing
Rhythm Perception and Production Workshop
Tatihou, France, 2003

Predicting rhythm perception from production using a Bayesian approach
Makiko Sadakata, Peter Desain & Henkjan Honing
Rhythm Perception and Production Workshop
Tatihou, France, 2003

Single trial ERP allows Detection of Perceived and Imagined Rhythm.
Peter Desain
Keynote RENCON workshop, International Joint Conference on Artificial Intelligence
Acapulco, Mexico, 2003

6.4 Conference organization

6.4.1 Rhythm Perception and Production Workshop

In 1998 we organized the Rhythm Perception and Production Workshop, held at the NIAS institute in Wassenaar. Around 36 invited speakers presented recent work in the field of rhythmic behavior. New at this 7th RPPW were the tutorials as an integrated part of the program. Dr. Peter Beek (VU) and Dr. Dirk Vorberg (Braunschweig) presented an overview of two paradigms (complex dynamics and mental timekeepers) that form a common basis of much research on rhythm and timing in human behavior. Many presentations referred to material highlighted in these tutorials, which led to a growing sense of relatedness between the two paradigms. In the presentations, another shift in direction occurred, in which the investigation of complex rhythmic behavior is favored more and more over the focus on tapping and synchronization tasks with simple isochronous stimuli. Furthermore, we noticed a growing use of computational models to explain the behavior. The excellent situation of the workshop at NIAS offered plenty of opportunity for informal contact between the participants. During the workshop it was decided to publish the proceedings as a book (Swets Zeitlinger).

6.4.2 Mini Seminar "Music Mind Machine"

Taking advantage of a large international group of visitors in September 2000 the group organized a mini-seminar that gave an overview of the recent developments in the research of all participants.

- Ric Ashley and Paul Trilsbeek *All his yesterdays, expressive timing in McCartney's vocal performances*
- Taylan Cemgil *On tempo tracking: Tempogram Representation and Kallman filtering*
- Henkjan Honing and Peter Desain *Identification of rhythmic categories*
- Justin London *Hierarchical Representations of Complex Meters*
- Kengo Ohgushi *Stroop-like effect in hearing: Cognitive interference between pitch and word for absolute pitch possessors*
- Erik Jansen *Harmonic inferences in the perception of brief melodies*
- Makiko Sadakata *Comparative Judgement of Melodic Musical Intervals and an accompanied Illusion*
- Renee Timmers, Peter Desain and Henkjan Honing *Amazing Grace*
- Renee Timmers and Peter Desain *Vibrato: questions and answers from musicians and science*
- Hank Heijink and Ruud Meulenbroek *A model-based study of left-hand fingering on the classical guitar*

6.4.3 Symposium on The perception and performance of vibrato (in conjunction with the International Conference on Music Perception and Cognition (ICMPC), Keele University, UK)

Convenors: Renee Timmers, Peter Desain and Henkjan Honing
Chair: Johan Sundberg

Vibrato in music performance has been a topic of research since the pioneering work of Seashore and his colleagues in the 1930s. After a period of dimished attention, the recent availability of automated acoustic analysis methods has created a new interest in the topic. Much effort has since been put into the understanding of vibrato from several perspectives. Research is, for example, concerned with the production of singer vibrato, the acoustic modeling of instrument and singer vibrato, the interrelationship between rate and extent, and vibrato characteristics during long and short tones.

This session, however, focused on the perception and performance of vibrato, with an emphasis on expressive use of vibrato in music performance. This research has been inspired by a large body of research on the expressive aspects of music performance, concerned with the study of the discrete aspects

(as opposed to continuous vibrato) of a performance, like note-onset timing or articulation.
Gleiser and Friberg presented their findings on the relationship between expressive variations and musical structure. Konishi, Imaizumi and Niimi focused on the emotional quality of vibrato and investigated whether listeners are able to recognized the intended emotion. Desain and Timmers discuss the contribution of musicians to vibrato research and vice versa; the extent to which musicians can be helped with scientific inquiries. Finally, Horii presented a study on the perceptual discriminability of vibrato characteristics and how this affects production control.

6.4.4 Symposium on Categorical rhythm perception and Quantisation (in conjunction with the International Conference on Music Perception and Cognition (ICMPC), Keele University, UK)

Convenors: Peter Desain, Henkjan Honing and Chris Jansen
Chair: Bruno Repp

This symposium held during the ICMPC in Keele, aimed at gaining insight into human categorization in the perception and interpretation of rhythmic patterns. First, it attempted to reveal the relationship between quantization and categorical rhythm perception. Second, it tried to make explicit the role of context. Third, it aimed to discover how empirical insights can be incorporated into models that may also be part of automated music transcription systems.

Eric Clarke gave an overview of the field, and provided the theoretical platform for the discussion by making a distinction between continuous (non-categorical) and discrete (categorical) aspects of rhythm perception. Peter Desain and Henkjan Honing presented experiments which aim to describe in detail the shape of the rhythm categories and how they are affected by tempo and metrical context. George Papadelis showed how these categories form and change with increasing musical experience of the listener. Next to presenting empirical work, Ed Large presented a dynamical model which is able to bring together these different aspects of categorization in rhythm perception. Furthermore he showed how to model hysteresis. Bruno Repp, who has contributed significantly to the study on categorical perception, chaired the symposium.

6.4.5 Site Visit

In 1999 a Site Visit was organized for anyone those in the preparation and realization of the PIONIER project. About 50 people accepted the invitation. Apart from a number of colleagues there were representations from a broad range of organizations involved in scientific research and funding, like the board of the KU Nijmegen, the PIONIER advisory board and NWO and its different departments. The program started with a presentation by Peter Desain about the aims of the project and the results obtained so far. Illustrated by virtual media and a live string quintet the concept of 'listening machines' was elaborated to explain how computational modeling gives us insight in the mental processes involved in appreciating music. Following the lecture the MMM-team gave demonstrations of their work in the studio and in an adjacent lecture hall. The site visit was concluded with a reception to which lustre was added by the string quintet 'Salon Traction'.

*"Imagine how wonderful it would be if we could create machines to listen as successfully. Small silent machines with ears […] But what would that mean for a machine to be able to listen? What mechanism needs to be inside to make sense of music, to recognise, experience and appreciate it ...." (*from Desain's site visit lecture; The listening vase courtesy of Ami van der Linde*)*

6.4.6 POCO-web workshop

In 2002, a number of scientists whho had been using the stand-alone version of POCO in the past, visited the Music Mind Machine lab for a workshop on POCO-Web. The participants were dr. Richard Ashley from Northwestern University, dr. Eric Clarke from the University of Sheffield, and dr. Luke Windsor from Leeds University. The purpose of this workshop was to get feedback from these experienced users about the usability of our software, both for themselves and for their students. We got much positive feedback:

POCO- Workshop in the MMM-lab, September 2002.

'The availability of POCO in a web-based version is a tremendous asset to the music research community. Having happily used POCO for many years in a shareware version on my own machine, it is a major step forward me and my research students (and other colleagues with whom I am in contact) to be able to have access to the same facilities without having to download software or buy the Lisp programming environment in which POCO is written, and from any internet-connected machine (Mac or PC). It will also mean that upgrading and development of the software will happen continuously and then become available immediately, and that suggestions for new possibilities will be shared by the large international community which already uses this indispensable research tool.' (Prof. Eric Clarke, University of Sheffield)

6.4.7 'Music Mind Machine' Lectures

The end of the project was marked by an afternoon of lectures on music cognition with the title *'Je weet niet wat je hoort*!' With support of the NWO Cognition program we organized a festive afternoon of lectures on the state-of-the-art of Music Cognition for a general audience.

Program 8 September 2003, Nijmegen:

- Opening by ir. R. de Wijkerslooth (KU Nijmegen, Chair of the Board)
- Introduction by Prof. dr. J. A. Michon (UL, psychology)
- prof. dr. D. Huron (Ohio State University, musicology)
- prof. dr. J. Bharucha (Tufts University, psychologiy)
- prof. dr. R. B. Dannenberg (Carnegie-Mellon University, computer science)

6.5 Work visits

- *Peter Desain* made a short work visit in 1999 to the IBM Watson Center, NYU and Tomandandy in New York.
- *Renee Timmers* visited from August to September 1999 the Music Cognition Group of Caroline Palmer at the Ohio State University, Columbus, Ohio, US. She attended group meetings and presentations and she got acquainted with the methods and research topics of the music cognition researchers.
- In August 1999 *Hank Heijink* visited Carnegie-Mellon University for a week to meet Roger Dannenberg and to present his work to computer music researchers and students.
- *Peter Desain* spend a 4 months sabbatical in 1999 in Japan. He stayed at Kyoto City University of the Arts (Gedai) in Japan as a guest of Prof. K. Ohgushi and at NTT's Basic Research Labs in Tokyo where he was hosted by Dr. N. Osaka. During these months, next to visits to colleagues in industry and academia, a new line of research into performance of traditional Japanese music was initiated. Furthermore he worked on a book on programming and music.
- *Dirk-Jan Povel* was Visiting Professor of Music Cognition at the School of Music of Northwestern University during the Spring quarter of 1999.
- *Peter Desain* visited Kyoto City University of the Arts and NTT Basic Research labs in Tokyo for collaborative projects in April 2000.
- *Peter Desain* and *Henkjan Honing*, visited the Music Technology Group (MOSART partner), University Pompeu Fabra, Barcelona, Spain. in 2001.
- *Renee Timmers*, visited Ric Ashley in Northwestern University, Illinois, USA in 2001 for two periods of about a month for collaborative research.
- *Henkjan Honing* was a research affiliate at New York University (NYU) for two months, starting in December 2002, a period during which he gave invited lectures at the Music and Music Technology Departments (NYU), the Music Department at Columbia University, and the Institute for Research in Cognitive Sciences (IRCS), Pennsylvania University.

6.6 Teaching, supervision

- *Renee Timmers* thought Music Psychology at the Royal Conservatory of The Hague (on the basis of 1 day per week).
- *Renee Timmers* supervised the internship of Laia Villadot (student psychology and flute from Barcelona) and an internship on 'Music theoretical literature on tempo and timing' of Shula Brouwer from the University of Amsterdam.
- *Marijtje Jongsma, Peter Desain*, and *Kathleen Jenks* taught the introductory course on experimental psychology to first year psychology students.
- *Marijtje Jongsma* assisted on a course 'hersenen and gedrag'
- *Peter Desain* thought a course in Music Cognition.
- *Henkjan Honing* taught courses in Theoretical Musicology and Philosophy of Science (of music) at the Music Department, UvA.
- *Peter Desain* served as external examiner for the PhD thesis of P. Keller (University of new South Wales), Peter Hannape, Université Paris VI, and Leigh M. Smith, University of Western Australia. He was *co-promotor* for the thesis defense of Renee Timmmers.
- *Henkjan Honing* was member of the PhD committee of W. v.d. Leur (UvA) and *co-promotor* for the thesis defense of Renee Timmmers and Hank Heijink (KU Nijmegen).

6.7 Editorships, review boards, program committee's

- *Peter Desain* is consulting editor of *Music Perception*.
- *Henkjan Honing* is advisory editor of the *Journal of New Music Research*.
- *Peter Desain* and *Henkjan Honing* served as reviewers for the International Conference on Music Perception and Cognition (ICMPC), International Computer

Music Conference (ICMC), Wedelmusic, Stockholm Music Acoustics Conference (SMAC), and International Conference of Music and Artificial Intelligence (ICMAI) conferences.

- *Peter Desain* and *Henkjan Honing* served on program committee's of the Rhythm Perception and Production Workshop (RPPW), International Conference of Music and Artificial Intelligence (ICMAI), Musical Constraints Workshop (CP01), Stockholm Music Acoustics Conference (SMAC), Brazilian Symposium on Computer
- Music (SBCM), Symposium on Computer Music Modeling and Retrieval (CMMR) and the Journées d'Informatique Musicale (JIM).
- *Peter Desain* and *Henkjan Honing* reviewed for the *Journal of the Acoustical Society of America*, *Music Perception*, *Perception & Psychophysics*, *Journal of Motor Behavior*, *Quarterly Journal of Experimental Psychology*, *Journal of Music Perception and Cognition*, *Psychology of Music*, *Journal of New Music Research*, *Computer Music Journal*, *Psychological Science* and *Cognitive Science*. They reviewed grant applications for NWO and the Natural Sciences and Engineering Research Council of Canada, as well as book proposals for McGraw-Hill.

6.8 Visitors

One important aspect of the project has to encourage experienced researchers from other institutions to visit the group. Such visits provided an opportunity for the visitor to give a tutorial or workshop to the group, to contribute to our series of Lab Presentations, or to speak at a NICI colloquium. During the visit they could also collaborate with the group on a research project. The visits were also intended to provide a basis for long-term collaborations between the visitor and the group.

- *Ric Ashley* is a Professor of Music at Northwestern University in the United States, He visited the group for a week in 1997. This visit was supported by a fund of SocW. As well as providing a workshop on the methods he has been using to analyse expressive timing in recorded jazz performance, he carried out an experiment in collaboration with the group. He also delivered a talk to a large group during the regular NICI colloquium, entitled *Do[n't] Change a Hair for Me: The Art of Jazz Rubato*. In 1998 he visited the group for four months. A Fulbright award supported the visit. He gave a lecture on cognitive correlates of musical structure, conducted research on communication between conductor and performer(s) and supervised a Project on Expressive Timing. In 1999 he again visited the group for a month. He advised PhD students and assisted with the preparation of presentations for the SMPC 1999. He returned for a short visit in 2001.
- *Ed Large*, a computer scientist from The Ohio State University, and University of Pennsylvania, Philadelphia, visited the group for a week in 1998 and gave to lecture on lecture on complex dynamics, coupled oscillators and beat induction models.
- *Dafna Naphtali*, composer and music technologist from NYU, New York, gave during a week workshops on Opcode Vision, OMS, Synth editors and Microphone techniques.
- *Caroline Palmer*, a music psychologist from OSU, Ohio visited the group for two days in 1998. She gave a tutorial and a NICI colloquium about her most recent paper, which gives an overview of research on links between musical structure and performance expression
- *Amandine Penel*, a PhD student in music cognition from CNRS, Paris, stayed with the group for two months in 1998 to do research on Todd's model of rabato and expressive timing decomposition in collaboration with Luke Windsor and

Peter Desain.

- *Bruno Repp*, music psychologist and senior researcher at Haskins Laboratory, New Haven, stayed with the group for two months in 1998. He gave lectures on his research on expression in musical performances and conducted research on timing and rhythmic structure in collaboration with Peter Desain.
- *Robert Rowe*, composer of computer music, Associate Professor at New York University, and author of Interactive Music Systems is in residence with the group for a year in 1998/1999 to work on his second book Machine Musicianship.
- *Marcelo Wanderly*, IRCAM, Paris, France stayed with the group in 2000 to collect measurement for his Research on expressive movements in clarinet performance.
- *Justin London*, Carleton College, Northfield, USA visited the group in 2000 for a week to work on metrical structure.
- *Kengo Ohgushi*, Kyoto City University of the Arts, Kyoto, Japan payed a short work visit in 2000.
- *Makiko Sadakata*, Kyoto City University of the Arts, Kyoto, Japan joined the group for a month in 2000 and in 2001 to conduct experiments on rhythm production and perception.
- *Luke Windsor*, University of Leeds, Department of Music, UK came over for a short visit in 2001.

6.8.1 Other visits (selection)

- *Yamaha* visited the group for an afternoon in 1998 in which they were presented ongoing research of the Vibrato Project.
- *Jan Nap* from NWO visited the group for a guided tour.
- Members of the *directory board of KU Nijmegen* and members of the *ministry of Education and Science* visited the group for a presentation.
- *N. Otsu* from the MITI in Japan visited the group for a tour and dicussions.
- A group of *high school teachers* visited the group in 1999 for a presentation.
- *Jens Arnspang*, Department of Computer Science, University of Copenhagen, Copenhagen, Denmark visited in 200 for a meeting to the initiate the EC MOSART project.
- *Peter Kronenburg*, University of Delft, The Netherlands visited the group in 2001
- *Benoît Mathieu*, ENST, Bretagne, France visited the group in 2001
- *Sonology Students*, of the Conservatory of The Hague visited the group in 2001 and in 2002 for a series of presentations, to learn about music cognition research and our approach.
- The board of the new *Faculty of Creative and Performing Arts of Leiden University* and the *Royal Conservatory* in Den Haag came to visit our group to hear about our research and to discuss possible exchanges.

6.9 Evaluations and awards

6.9.1 KNAW Evaluation

January 2002 a peer review-committee visited the NICI to evaluate the renewal of its KNAW recognition as a graduate school. The MMM-group gave a number of presentations and demonstrations. This international panel of experts came to the following conclusion:

> *'The Pioneer project Music, Mind, Machine establishes a visible center for work largely neglected area of human cognition. The quality of the work was very good.'*

6.9.2 Swets and Zeitlinger Distinguished Paper Award

A *Swets and Zeitlinger Distinguished Paper Award* was earned for the paper: *"On tempo tracking: Tempogram Representation and Kalman filtering"* by Ali Taylan Cemgil, Bert Kappen, Peter Desain and Henkjan Honing. The 25 nominations were preselected by the International Computer Music Conference (ICMC) 2000 paper selection committee. The final selection was based on the importance of the paper for the field of computer science, as well its suitability for publication in JNMR, novelty and presentation:

> *'The prize-winning paper by Cemgil, Kappen, Desain and Honing addresses tempo tracking, the automated process of deriving the tempo from a performance containing expressive timing and tempo variations. [...] We believe that the method described in the winning paper has significant applications both in offline transcription and real-time performance situations.[...] The committee was impressed by the wide range of musical situations in which this method can be used, and particularly by its potential for real-time performance.'* [from the jury report]

6.9.3 Hickman Award

Renee Timmers received the *Hickman Award* (SRPMME) for best paper in music performance studies for her paper *"On the contextual appropriateness of performance rules"*.

> *'The standard of entry was extremely high, and the competition for the award was fierce. However, the advisory committee felt that the proposal offered a rigorous and unique contribution to topics central to the conference theme. Many congratulations'* [from the jury report]

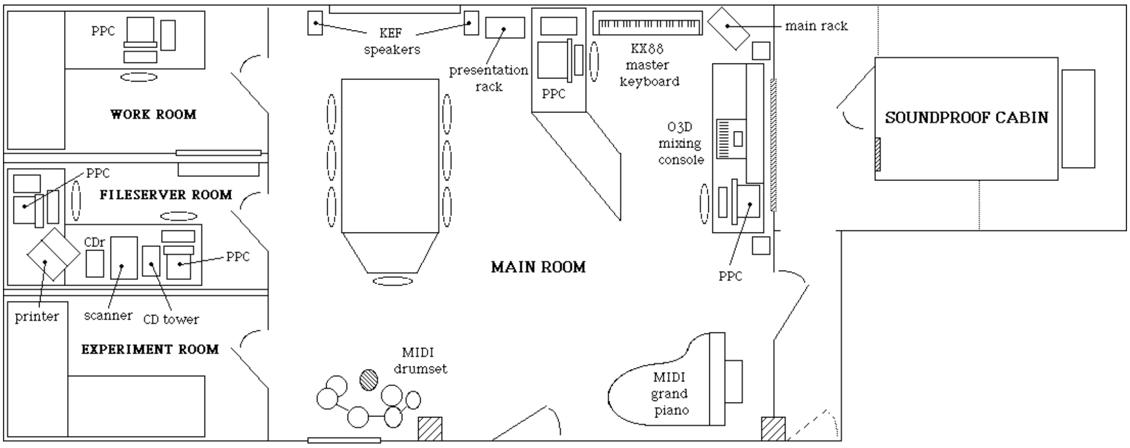
6.10 Patents

A patent application has been filed by Peter Desain ("*Method and system for detecting specific brain activity*", application number 2076635.8). It describes how the rhythmic pattern that someone hears or imagines can be detected in a single trial ERP signal. This algorithm will form the basis of a system that allows severely handicapped people to communicate and control devices using imagined temporal patterns. Together with prof. S. Gielen (Biofysics, KU Nijmegen) an STW grant application for this research has been submitted.

7 Facilities

7.1 Accommodation

The MMM group used the laboratory located in the basement of the Spinoza building. The building of the lab/studio in BK-10 was coordinated by the department of building affairs. In this multimedia environment, experiments are conducted, presentations are given, and analysis and synthesis of musical material is carried out.

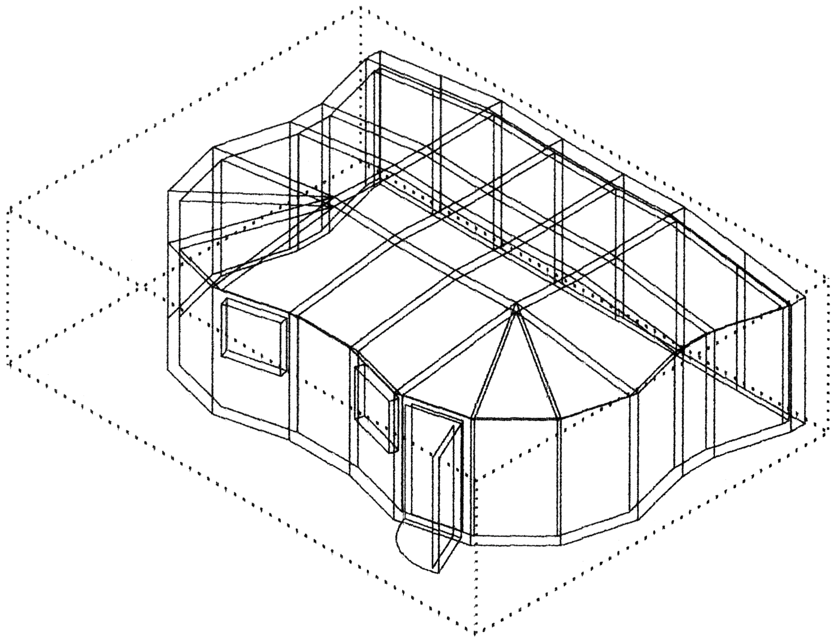


Layout of the MMM-lab

The department of electronics took care of cabling and several facilities that had to be custom-designed.

There are three separate small rooms: one for experiments, one containing file servers and peripherals, and one for storage of equipment and instruments. A large room is used for presentations and data processing.

Digital audio routing is handled through the fully digital (and computer controllable) Yamaha O3D Digital Mixing Console that also supplies effect processing. Midi routing is handled through an Opcode Studio 5 Patcher interface and several Roland A-880 Patchers. Synthesizers are based on physical modelling (Yamaha VL1-m), sampling (Kurzweil 2500r) and General Midi (Yamaha MU90). Audio capture is handled by a DigiDesign AudioMedia III card in a Macintosh computer, via a Millennia Media Microphone Amplifier. Other audio recording is done on a Nakamichi RX-505E cassette deck and a Panasonic SV-3800 DAT, plans for a digital 8-track recorder were postponed. Audio amplification is through a Quad 707 amplifier and KEF RDM Monitors or Behringer Powerplay Headphone Distribution Amplifier. The presentation rack contains a NAD 512 CD-player, Rotel RC 970BX Mk II Stereo Control Amplifier and a Samsung Video Tape Recorder, while presentations and interviews can be captured using a Panasonic NV-M50EG Videocamera. A Yamaha Disklavier, Yamaha KX88 Midi Master Keyboard, Roland P-160 MIDI controllers, Peavy PC 1600 MIDI controllers, a Yamaha DTX Midi drumset and a Yamaha WX11 wind controller complete the set-up.



Layout of the soundproof recording room

All analog and digital audio, MIDI, and video is distributed to the corners of the room via wall-trunking and patch bays on the instrument racks. Next to the lab there is a soundproof recording room, which is suitable for recording our grand piano as well as larger ensembles, or for conducting listening sessions with larger groups. The room has good acoustical properties, which makes it comfortable for musicians to play in.
In the lab there is a soundproof and shielded cabin for conducting ERP experiments. There are audio, video and MIDI connections between the studio and this ERP cabin.

7.2 Computing facilities

The group mainly uses Apple PowerMac G4, iMac and PowerBook computers. Central in the set-up is an AppleShare IP file server for the whole group containing applications, LISP code, administrative data and MIDI and sound archives. This year with the renovation of the building the data network has been renewed. This network is capable of handling 100Mbit connections on every outlet, although currently most of them are restricted to 10Mbit. Automatic backups of all machines are made daily using the TSM backup solution provided by the UCI.

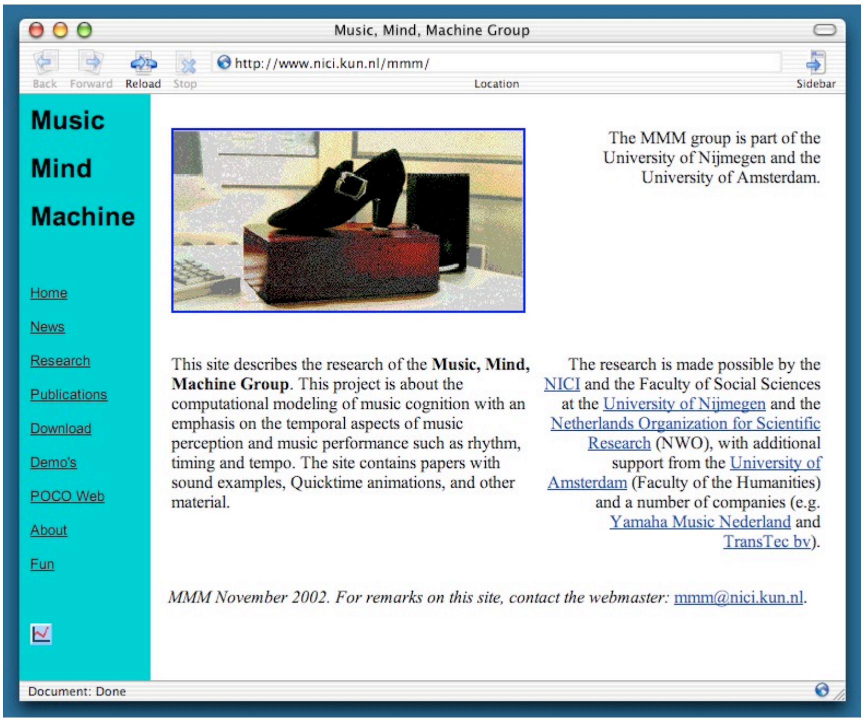
7.3 Guest use

The studio is also available for other researchers who want to use the Disklavier grand piano or other audio and MIDI equipment for experiments. Some technical support was provided by Paul Trilbeek. The studio was used by Katharina Spalek for recording speech, by Jules Ellis for making CD recordings. Laia Villadot recorded piano chords for a user-interface project with Ab de Haan. Furthermore, the facilities have been used by the psycholinguistics section (Ton Dijkstra) of NICI for audio recordings of stimulus material and Marcello Wanderly (IRCAM, Paris) for movement registration of clarinet performance.

8 Dissemination

8.1 MMM Website

The project maintains two websites: our internal website containing agendas, forms, addresses and other shared resources, and the publicly accessible MMM site (www.nici.kun.nl/mmm and www.hum.uva.nl/mmm). On this latter site information on the project and all articles (with sound examples and QuickTime animations) can be found. With approximately 14000 visitors to the home page per year, the website is very popular and accounts for more than half of the total NICI website traffic.



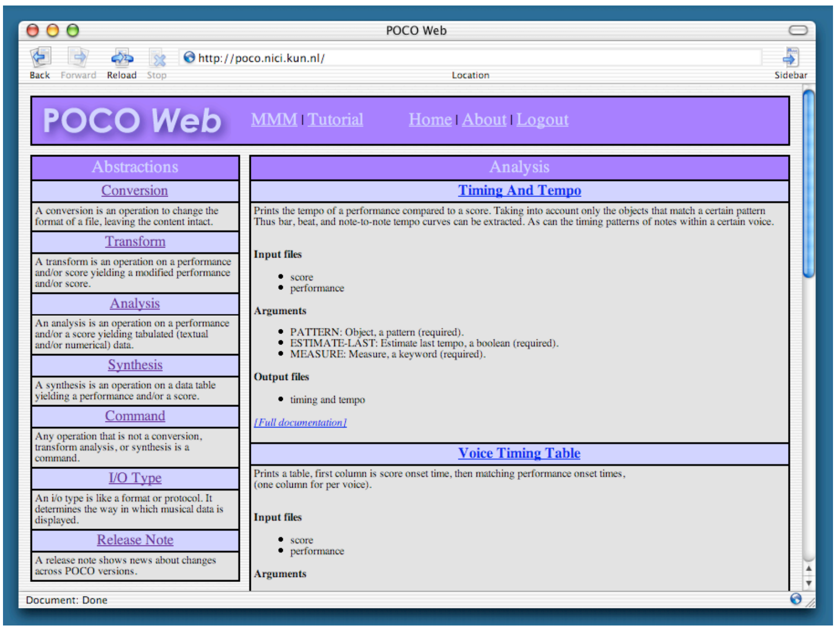
Home page of the MMM-website at www.nici.kun.nl/mmm

8.2 CD-ROM containing the MMM website (*enclosed*)

This CD-Rom is a copy (as of September 2003) of the internet accessible website of the 'Music, Mind, Machine' (MMM) project. However, some links (e.g., 'Data Archives') are not included because of size restrictions of the CD-Rom. These links, as well as external links, are indicated in red. The online MMM-website can be found at the addresses mentioned above.

8.3 *POCO*-web

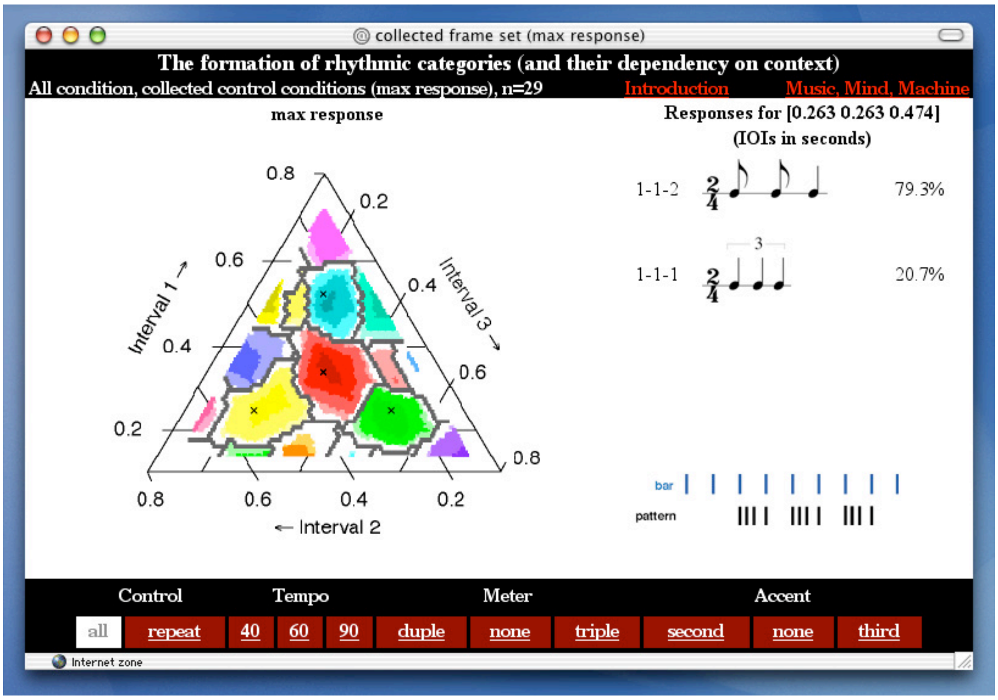
POCO (Honing, 1990; Desain & Honing, 1992) is a collection of tools for analyzing, transforming and synthesizing musical performances. The first version dates from 1988, and since then POCO has grown enormously and now contains hundreds of modules. The main users of POCO are students and researchers in music cognition, for example at North Western University (Evanston, USA), and Sheffield and Leeds universities in the UK. POCO runs only on a Macintosh with Macintosh Common Lisp, but with the POCO-Web project, an important part of the software has become available to a larger group of researchers and students via a standard Web browser on any operating system. Users can upload their data and download the result. Functions of POCO that are available in this web version are for example conversion of MIDI files to text or table files, merging and concatenation of musical data, filtering of musical data, several score-performance matching algorithms, timing and tempo analysis and several more. The software can be accessed on www.nici.kun.nl/mmm under the heading 'POCO-web'.



Snapshot of POCO-web

8.4 The quantization research demo

Listeners to music do not perceive rhythm on a continuous time scale. Instead, rhythmic categories are perceived that function as a reference relative to which deviations from strict timing are perceived. These deviations are experienced as the expressive character of the performed rhythm. In this research we investigate the effect of context (e.g. meter, tempo, accent) on the perception of rhythmic categories. A first version of an elaborated quantization demo allows the user to explore all our experimental data and the results obtained. At the bottom of the demo the various experimental conditions are indicated, the ternary plot (*time clumping map*) shows the responses for the different stimuli. When you click on a point in the map the corresponding stimulus is shown at the right-hand side. You can play the stimulus, listen, and click on the response label to see the subjects' responses in music notation.

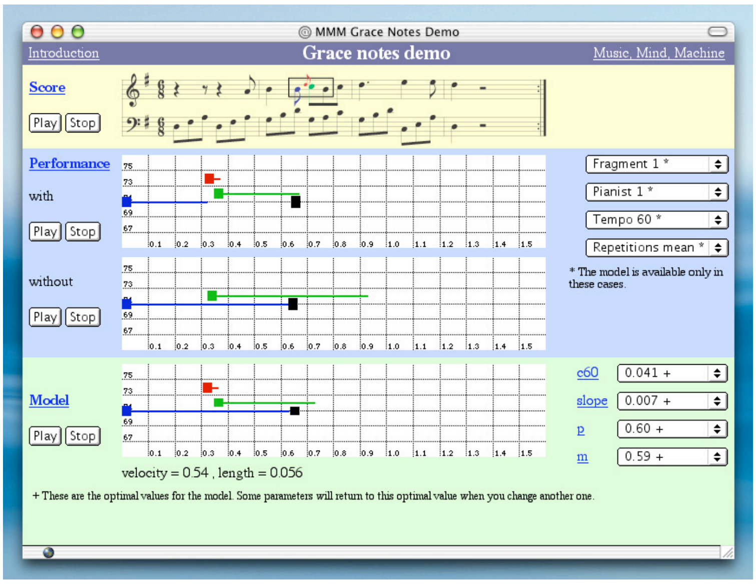


See http://www.nici.kun.nl/mmm under the heading 'Demo's.'

8.5 The grace notes research demo

The grace note web demo is a presentation of the data and a demonstration of the grace note model as described in Timmers *et al*. (2002).
The score of the performances is given at the top. The grace note is colored red, the previous note blue and the main note green. You can listen to all recorded performances: 7 repetitions of three fragments by 16 pianists in 7 tempi in two conditions (with/without grace note). You may also explore ways

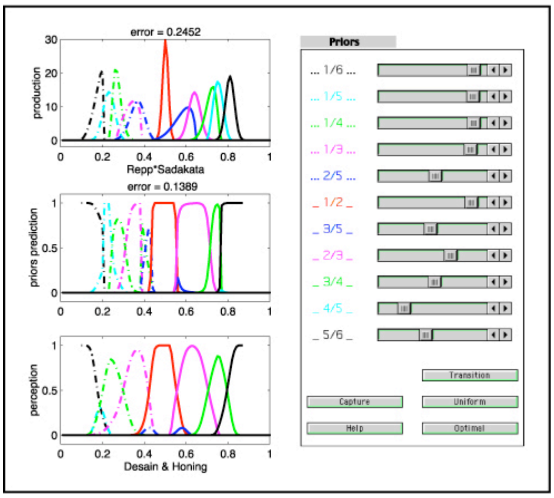
of inserting the grace note using a model and changing the parameter settings. The current version still only supports MIDI playback, the next version will allow you to listen to the audio recorded from the MIDI grand piano in our studio.



See http://www.nici.kun.nl/mmm under the heading 'Demo's.'

8.6 Bayes demo

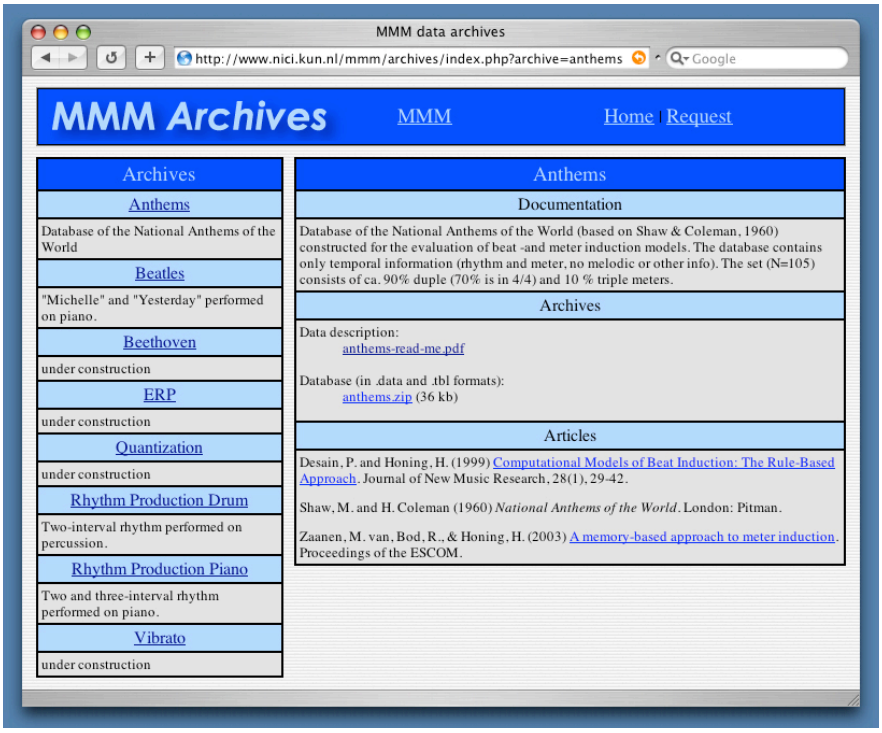
This video shows a demonstration of the Bayes method. We use this probabilistic rule to predict perceptual data accurately from production data, by manipulating a set of a priori likelihoods for the rhythms. In the video they change from uniform to optimal and vice versa.



Screen shot of Bayes-demo.

8.7 MMM archives

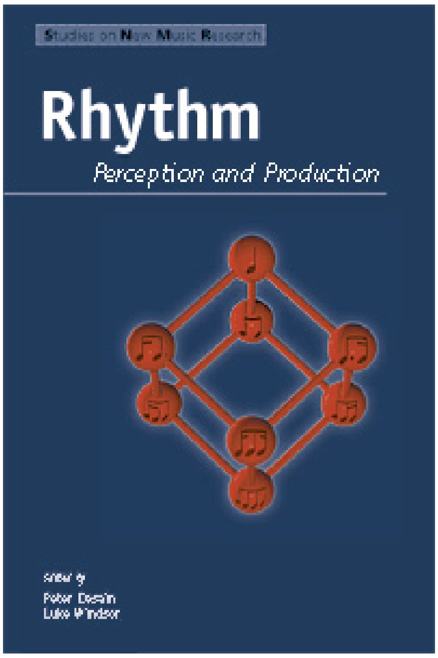
The MMM-archives on our website contains all experimental data (both stimuli and responses) and is made freely available to researchers. In this way our research can be replicated and build upon more easily.



Screen shot of MMM archives.

8.8 Books

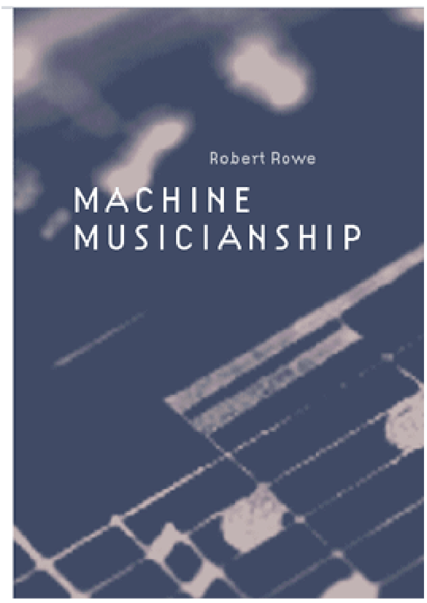
8.8.1 Desain, P. and L. Windsor (2000) *Rhythm perception and production*. Lisse, NL: Swets and Zeitlinger.



This book is a primer for those interested in the perception and production of rhythm, giving readers both an overview of recent research in the introductions to each section and a broad selection of chapters dealing with more detailed studies. It consists of contributions by some of the most respected investigators in the fields of motor behavior, timing control, music cognition and psychology and arose out of the 7th Workshop on Rhythm Perception and Production held in Wassenaar in 1998.

The book contains an audio CD with examples and stimulus material and can be ordered from: Swets & Zeitlinger, Publishers, P.O.Box 825, 2160 SZ Lisse, The Netherlands, fax (+31) 20 865 9741, e-mail: orders@swets.nl

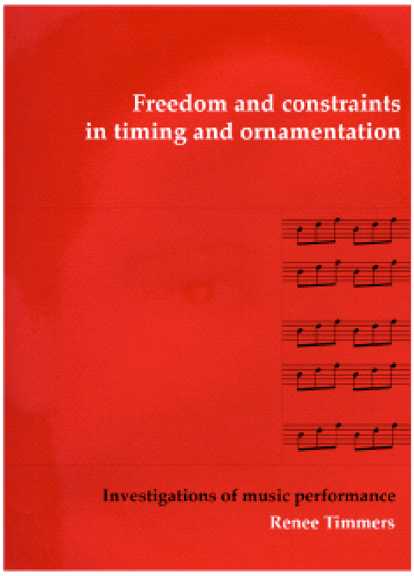
8.8.2 Rowe, R. (2002) *Machine Musicianship*. Cambridge, MA: MIT Press [4]



Robert Rowe has been a guest of the project during his sabbatical from NYU. In this period he finished this book which focuses on machine understanding of music. The book explores the technology of implementing musical concepts in computer programs. Apart from dealing with performance it addresses the difficult issues of machine listening and makes important theories about those processes easily accessible to students in a practical way.

The book contains a CD-rom with programming examples in MAX and can be ordered from MIT Press (www.mitpress.com)

8.8.3 Timmers, R. (2002) *Freedom and constraints in timing and ornamentation. Investigations of music performance*. Maastricht, Shaker Publishing. (incl. CD-ROM with sound examples.)



A musical performance is expressive and this expression conforms to several rules. Expression can be defined as what musicians add to the music as notated in the score and can be measured as variations in timing, dynamics, and intonation. The rules are the conventions and principles that musicians hold and make up the conditions under which the variations arise. Besides these rules, the musician's interpretation plays an important role as well.

The book combines a number of studies that investigated the liberties and constraints of these rules, concentrating on piano performances of classical music. The first study shows that the diversity in interpretation increases with the complexity of the music performed. The second study demonstrates that the quality of a performance depends to a considerable extent on the expressive context. The last two studies outline the structure of the timing of grace notes in a theme from Beethoven, resulting in a computer model of grace note timing.
This book can be ordered at Shaker Publishing (www.shaker.nl).

8.9 Press and public relations

After a press release by the NWO and the communication office of the university, the project got a great deal of press attention (national and regional newspapers, radio and television) to a total of about 200Kfl in 'bought advertisement' equivalent. A folder with articles in the Dutch press is available upon request. Some of this coverage gives a good impression of the project and its goals, but not all of it is focused on the central issues of the research.

Three documentaries appeared on the TV networks:

- A *BBC World News* item on grace notes gave a short impression on our work on modeling the behavior of musical ornaments under tempo transformations.

- A documentary about work in our group was filmed by Maria Ramos and broadcast as part of the VPRO '*Noorderlicht*' series. In the documentary, called '*Het mysterie van vibrato*', the research is explained with the aid of animations, music performances and interviews. Related work at IRCAM (Paris) is also shown.

- Teleac devoted a program in their series '*Wetenshoppen*', a science program for youngsters, to our work on beat induction. The research of the MMM team and our guest researchers Ric Ashley and Robert Rowe, is presented in relation to the investigations of colleagues Hanna Bosma (UvA), Lieke Peper (VU) and Rokus de Groot (RUU). The script and help with realization of these programs required a large effort on our part, but in the end we were very happy with the quality of both programs. They make it possible to present our fascination, aims and results to a large audience.

9 Funding and related projects

The PIONIER grant was matched by a large contribution from KU Nijmegen (NICI, SocW) and additional support from the University of Amsterdam (UvA). MaGW supplied extra travel money for the project. A number of sponsors contributed on a smaller scale, they are mentioned below (in alphabetical order):

- *CvB, KU Nijmegen*: special PIONIER matching (used for MMM-studio)
- *IM, KU Nijmegen:* support in management courses and group training
- *KNAW, NWO and KU Nijmegen:* contribution in organizing RPPW workshop
- *MOSART (EU IHP program):* mobility costs, postdoc and junior researcher
- *VU:* junior researcher (one year)
- *NICI, SocW*: contribution to costs MMM-studio
- *NWO-Cognitie programma*: funding for preparing Limited Turing Test on Art and Cognition
- *NWO-Cognitie programma*: substantial contribution in organizing the MMM-lectures
- *NWO-SION*: project on disclosure of large music databases, postdoc
- *NWO-STW*: project on automatic music transcription, postdoc, PhD student, music technologist
- *SocW / Internationalisering, KU Nijmegen*: contributions in organizing the MMM-lectures and a number of visitors
- *Transtec*: reduction audio equipment
- *UCI, KU Nijmegen*: POCO web project, music technologist

- *Utrecht Court*: fee for expert report on comparison MIDI-files
- *Yamaha Music Nederland*: reduction on musical instruments and electronic equipment

Some personal funds were received by:

- *Marijtje Jongsma* received an IFCN Fellowship
- *Renee Timmers* received grants from NWO and the Hendrik Müller foundation for publication costs of her book and a travel grant from NWO for a work visit to the US
- *Peter Desain* was awarded a CANON fellowship for a work visit to Japan
- *Henkjan Honing* received grants from KU Nijmegen and UvA for a research visit/sabatical at New York University (NYU) in the winter of 2002.

10 The future of MMM

Sometimes it proves impossible to achieve what one wants. In September 2003 the PIONIER project has formally come to a close. In the course of the year 2002, it became clear that the MMM team would not be able to continue with all three disciplines involved on an equal footing. In the short rum this fact has important consequences for our research. It does, however, not signal the end of our activity in the field.

Since we started the MMM adventure, we have become even more convinced that music cognition research really needs an interdisciplinary approach. It is our passion, expertise and mission to bring together the sciences of music, of the mind, and of computation. Many of our fundamental human abilities are used in music making and listening and a lot that is going on in the world, everywhere and everywhen. In that light the study of music behavior is no luxury at all, contributing, as it does, in an essential way to the understanding of human cognition and human nature.

11 List of abbrevations

AIO	Assistent in Opleiding (PhD student)
BEIAP	Bureau d'etude "Introduction a la Psychoacoustique"
CNRS	Centre National de Recherche Scientifique
CP01	Workshop on Constraint Programming and Music
DIKU	Datalogisk Institut Københavns Universitet
ICMAI	International Conference of Music and Artificial Intelligence
ICT	Informatie en Communicatie Technologie
ICMC	International Computer Music Conference
ICMPC	International Conference on Music Perception and Cognition
IFCN	International Federation of Clinical Neurophysiology
ILLC	Institute for Logic, Language and Computation
IM	Integraal Managament (KUN department of Integral Management)
IRCAM	Institute de Recherche et Coordination Acoustique/Musique
JIM	Journées d'Informatique Musicale
KNAW	Koninklijke Nederlandse Akademie van Wetenschappen (Institute of the Royal Netherlands Academy of Art and Sciences)
KTH	Kungl Tekniska Högskolan (Royal Institute of Technology)
KUN	Katholieke Universiteit Nijmegen (Catholic University Nijmegen)
LMT	Stichting voor Literatuur-, Muziek- en Theaterwetenschappen (Foundation for Literary Studies, Musicology and Drama Research)
MOSART	Music Orchestration Systems in Algorithmic Research and Technology
NIAS	Netherlands Institute for Advanced Study in the Humanities and Social Sciences
NICI	Nijmegen Instituut voor Cognitie en Informatie (Nijmegen Instititute for Cognition and Information)
NVP	Nederlandse Vereniging voor Psychonomie
NWO	Nederlandse Organisatie voor Wetenschappelijk Onderzoek (Netherlands Organisation for Scientific Research)
NWU	Northwestern University, Evanston, USA
OFAI	Australian Research Institute for Artificial Intelligence
OIO	Onderzoeker in Opleiding (PhD student)
RPPW	Rhythm Perception and Production Workshop
SGW	Stichting voor de Gedragswetenschappen (Foundation for Behavioral Sciences)
SION	Stichting Informatica Onderzoek Nederland (Netherlands Computer Science Research Foundation)
SMAC	Stockholm Music Acoustics Conference
SNN	Stichting Neurale Netwerken (Neural Networks Foundation)
SocW	Faculteit Sociale Wetenschappen (KUN Faculty of Social Sciences)
SRPMME	Society for Research in Psychology of Music and Music Education
STW	Stichting voor de Technische Wetenschappen (Technology Foundation)
TA	Technische Assistent (Technical Assistant)
TMR	Training and Mobility of Researchers
UBN	Universiteits Bibliotheek Nijmegen (KUN University Library)
UCI	Universitair Centrum Informatievoorziening (KUN Center for Information services)
UvA	Universiteit van Amsterdam (University of Amsterdam)
WWW	World Wide Web
VU	Vrije Universiteit (Free University)