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LABORATORY NOTE

The Institute for Music Physiology and Musicians' Medicine

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Abstract The Institute of Music Physiology and Musicians' Medicine of the University of Music and Drama in Hannover, Germany, is a unique Institution in Europe whose scope includes teaching the basics of music physiology and musicians' medicine and research into the physiological and neurobiological principles of professional music performance and music perception. Furthermore, the institute conducts research into the causes of occupational injuries in musicians and provides means for prevention, diagnosis and treatment of such injuries.

Keywords Musicians' medicine · Music physiology · Emotions · Stroke rehabilitation · Music performance · Focal dystonia

Introduction and history

The Institute for Music Physiology and Musicians' Medicine of the University of Music and Drama in Hannover, Germany, is a unique institution in Europe whose scope includes the following:

- Teaching the basics of music physiology and musicians' medicine.
- Research into the physiological and neurobiological principles of sensorimotor learning in musicians of professional music performance and of music perception.
- Research into the causes of occupational injuries in musicians.
- Prevention, diagnosis and treatment of such injuries.

The Institute was founded in 1974 as the Institute for Experimental Music Pedagogics under the chairmanship of Prof. Richard Jakoby. Dr. med. Christoph Wagner, who directed the institute from 1974 till 1993, renamed it in 1984 as The Institute of Music Physiology. In 1994 Dr. med. Eckart Altenmüller succeeded Dr. Wagner as the head of the institute. To emphasize the medical aspect of the institute, it is now called The Institute for Music Physiology and Musicians' Medicine. Since 2003, the Institute has been part of the Center of Systems Neuroscience in Hannover (ZSN, Hannover) and offers a PhD program for students graduating in life sciences and musicology. The director of the Institute is a member of the board of the ZSN.

Overview of research fields

Basic research programs at the Institute for Music Physiology and Musicians' Medicine are focused on emotional reactions to music and musical memories as well as on sensorimotor learning in musicians. Emotional reactions to music and the relation of musical memories to emotions are studied in several approaches based on psychological methods (e.g., continuous self-report, character inventories) as well as on physiological measurements (e.g., skin conductance, heart rate). Experiments are performed in individual laboratory settings as well as in a newly developed internet approach. In the future we plan further experiments to investigate both the social contexts and EEG aspects of strong emotional reactions to music.

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The acquisition and maintenance of sensorimotor skills in musicians are investigated with special interest in the neurobiological principles (e.g., audiomotor integration) as well as in physiological, psychological and pedagogical aspects (e.g., sensorimotor precision in professional musicians, practice strategies, biographical predictors of sensorimotor skills).

Clinical research programs aim at a better understanding of the two central challenges in Musicians' Medicine: focal dystonia in musicians and pain syndromes in musicians. A number of projects are conducted to investigate the etiology and pathophysiology of these disorders and to improve the diagnostic tools and therapeutic options. Further clinical studies are carried out to illuminate the applicability of music-supported training of motor functions in the rehabilitation of patients after stroke.

Basic research

Correlates of strong emotion in music

Emotions are important factors that strongly influence everyday life decisions. Research into this field became the topic of an increasing number of studies during the last decade. The emotional impact of music was found to be the most important reason for listening to music (Panksepp 1995). This suggests that music can be used as an ideal stimulus for research concerned with emotional reactions. Emotions are classically defined to consist of three components (Scherer 2004): a subjective feeling component, a physiological response, and a behavioural or motor response. For every single component there are several methodological approaches. However, the distinct relations between theses components are still unclear, especially over a period of time. Since music develops over time, and the emotional reactions of the listener can be expected to change during the course of a piece as well, continuous measurements of emotional components while one is listening to music offer some exciting opportunities for the understanding of emotion.

The Institute's current project concerned with emotional reactions to music is being conducted in collaboration with Professor Reinhard Kopiez from the Institute for Research in Music Education. Furthermore, it is part of the Interdisciplinary Research Group *Acoustical Communication of Affects in Non-Human Mammals and Humans*, supported by the German Research Foundation (DFG).

In order to combine the available methods of continuous measurement of physiology and motor responses, Nagel et al. (2007) developed the EMuJoy software that allows the subject's continuous self report of feelings in a two-dimensional emotional space while listening to music. Additionally, the participants were asked to report "chills," or strong emotion-related bodily reactions, such as goose bumps or "shivers down the spine." An exploratory pilot study combining continuous measurements of all three emotional components and chills brought interesting new information about general emotional reactions to music.

1. The emotional components seem to be independent of each other. Changes in feelings are reported in accordance to physiological arousal in response to events such as the entry of a voice or the beginning of a new part. However, participants also reported changes in their feelings without showing any measurable physiological reaction and vice versa. Mimic responses (facial muscle EMGs) were rare and did not synchronize with feelings and physiological responses.
2. Chills, as a paradigm for strong emotional responses to music, proved to be dependent on familiarity with a musical style and on personality factors, such as "reward dependence" or "sensation seeking." Chills were also found to be related to changes in loudness; however, no distinct acoustical pattern could be identified that induces chills in a reflex-like way. Grewe et al. (2005, 2007) presented evidence that chills are based on a cognitive evaluation of the musical stimulus or, in other words, that chills are bodily reactions based on (subjective) feelings.

Several follow-up studies were designed and have been recently performed in order to allow a more detailed insight into the relation of emotional components and chills as well as into the influence of social situations on emotional responses. In the future, further methods, such as electro encephalography (EEG), will be used to reveal the cognitive processing of emotion.

The relation of musical memories to emotions and the limbic system

In this research project, the effect of emotions induced by music on the episodic long term memory (Tulving 1985) encoding and retrieval of music are investigated. Emotional events and facts are remembered better than non-emotional ones. In many studies using words or pictures, an advantage for highly emotional material compared to neutral material was shown (e.g., Kensinger and Corkin 2003; Bradley et al. 1992). Music can induce strong emotions (Krumhansl 1997; Panksepp 1995), and can be remembered, possibly in connection with these emotions, even years later. Strong emotions related to the musical experience seem to facilitate memory formation.

In three proceeding studies, the emotional appraisal of excerpts from piano music by J.S. Bach (Eschrich; Münte and Altenmüller 2005) and symphonic film music were and are investigated according to the two-dimensional valence-arousal model by Russel (1980). Additionally, the episodic memory for these excerpts was tested in a recognition test. We wanted to find out how emotions influence episodic musical memories experienced in the laboratory. We hypothesized better recognition performance for pieces which are rated with high arousal and highly positive valence.

In Experiment II subjects were divided into two groups. The "Emotion group" rated the emotional effect of the music, while the "Detection group," as a kind of control group, estimated the length of the musical pieces. The Emotion group was expected to show better recognition performance than the Detection group, because members of the Emotion group focused their attention on the emotions induced by the music and thus should have processed more deeply (Craik and Lockhart 1972). The role of structural features, such as tempo, loudness, repetition of motives, recognizability of melody, and complexity, in memory formation and retrieval was examined.

The currently ongoing Experiment III is designed similar to Experiment II with some changes. We use a smaller number of stimuli selected from the stimulus pool of Experiment II, we ask for induced valence and arousal as well as for recognized valence and arousal. In this experiment we additionally take physiological measures (heart rate, skin conductance level and skin conductance response as well as respiration rate) to confirm that the emotions induced by the music as rated by the participants are really induced.

After we have successfully finished Experiment III, we are planning an fMRI experiment with a similar design for investigating the brain regions involved in musical long-term memory in relation to emotions.

The acquisition of instrumental skills in musicians: neurobiological and physiological principles

Performing instrumental music at a professional level is one of the most demanding human accomplishments. Music making involves the integration of sensory and motor information and requires the precise execution of highly complex physical movements under continuous auditory feedback. The neurobiological and physiological principles underlying the acquisition and maintenance of sensorimotor skills in professional musicians are in the focus of several research projects at the Institute of Music Physiology and Musicians' Medicine. As examples, two of these studies are described in the following section:

a) A longitudinal DC-EEG study was conducted to investigate when and how the neuronal basis of audio-motor integration is established. We observed the changes in cortical activation patterns induced by short term (20 min) and long term (5 weeks) piano learning in novices (Bangert and Altenmüller 2003). DC-EEG potentials were recorded in 17 subjects with no experience of piano playing who had to perform three sets of tasks on a computer-piano that allowed selective examination of auditory and motor aspects of performing: (1) A set of 60 purely auditory (listening to short monophonic piano sequences) and 60 right-hand motor tasks (arbitrary finger tapping on a silent piano keyboard); (2) a computer-controlled training phase (re-playing of short acoustically presented right-hand melodic sequences with instant auditory feedback) which aimed at audio-motor binding; (3) another set similar to (1). Furthermore, the novices worked with an adaptive training software (as designed for part (2) of the experiment) over a period of 5 weeks. While the 'map' group was allowed to learn the standard piano key-to-pitch map, for the 'no-map' group the keyboard was manipulated and random assignment of keys to tones was presented. Auditory-sensorimotor EEG co-activity occurred within 20 min only. The effect was enhanced after 5-week training, contributing elements of both perception and action to the mental representation of the instrument. The 'map' group demonstrated significant additional activity of right anterior regions. We concluded that audio-motor co-representation was already established during the very first minutes of piano training, and it was consolidated during subsequent weeks of practicing. This coactivation may provide the basis of any virtuosity that can be achieved later on. The anterior right region that appeared active in both kinds of probe tasks seems to have properties of a supramodal neural network suitable for translating sound into motion, i.e., it may provide musicians with an interface map.

b) Playing instrumental music requires movements with highest temporospatial precision. We investigated the degree of timing precision displayed by professional pianists using a MIDI (Music Instrument Digital Interface) keyboard. MIDI allows a computer-based analysis of performance parameters such as loudness and timing parameters, the latter with a precision in the range of milliseconds. In a study with 13 professional pianists, the evenness of scale playing in the legato style (notes are played in a smooth, connected manner) was examined with special focus on hand and finger coordination in the thumb-under movements in the outward playing direction as well as finger cross-over maneuvers in the inward playing direction (Jabusch

2006). The pianists played sequences of 10 to 15 C-Major scales in the legato style over two octaves in both playing directions and with each hand separately. Scales were played using the regular C-Major fingering (1-2-3-1-2-3-4-1-2-3-1-2-3-4-5 and reverse). The tempo was metronome-paced and standardized at 120 beats per minute for a quarter note, and scales were played in 16th notes. As an example, results are reported for the right hand tests. For over all scales of all pianists, the mean standard deviation of inter-onset intervals was 8.1 ms in the upward playing direction and 8.9 ms in the downward playing-direction indicating an extraordinarily high level of evenness in playing. This was achieved by a peculiarity in the coordination of the thumb-under movements (3-1 and 4-1 fingering in the upward playing direction) and finger cross-over maneuvers (1-3 and 1-4 fingering in the downward playing direction). In the preparation phase of thumb-under movements in the upward playing direction, there was a consistent finding of significantly shortened tone durations of notes preceding the tones played by the thumb. This resulted in minimal gaps (mean 13.0 ms) between the notes at the 3-1 and 4-1 fingering positions. In the downward playing direction, such significant shortening of tone durations in the preparatory phase of finger cross-over maneuvers was seen in the 2-1 fingering positions indicating an early pronation movement of the hand facilitating the 1-3 as well as 1-4 finger cross-over maneuvers. This study showed that professional pianists played with little gaps in the thumb-under movements and in finger cross-over maneuvers although they performed in the legato style. Impaired auditory perception in the temporal proximity of key strokes due to auditory forward and backward masking phenomena may explain that such irregularities in the note offsets are not perceived and therefore not a focus of practicing. It may be speculated that auditory feedback is the leading feedback mechanism during the acquisition of motor skills in pianists since the aforementioned "motor deficit" (gaps in legato playing) coincides with the phenomenon of masking in the auditory perception in the temporal proximity of key strokes.

Ongoing studies in this field are focused on

- Behavioral and biographical predictors for the acquisition of sensorimotor precision in children pianists and those for the maintenance of high levels of sensorimotor precision in professional pianists.
- Analysis of instrumental performance (3D movement analysis, electromyography, and analysis and expert ratings of audio recordings) in drumming.

Applied clinical research

Musician's dystonia

Focal dystonia in musicians is a central focus of our clinical research. Musicians' dystonia is a task-specific movement disorder which manifests itself as a loss of voluntary motor control in extensively trained movements. In many cases, the disorder terminates the careers of affected musicians. Approximately 1% of all professional musicians are affected. Until today, the pathophysiology of the disorder is unclear. Neuroimaging studies point at dysfunctional (or maladaptive) neuroplasticity as being involved in the etiology. Support for this theory comes from a functional brain imaging study performed on musicians with focal dystonia. In contrast to healthy musicians, musicians with hand dystonia showed a fusion of the digital representations in the somatosensory cortex, reflected in a decreased distance between the representation of the index finger and the little finger when compared to healthy control musicians (Elbert et al. 1998; Altenmüller 2003). Since skilled motor actions are necessarily bound to intact sensorimotor feedback loops, it is possible that the loss of motor control in musician's dystonia might be induced by the aforementioned alterations. At present, however, it cannot be excluded that the observed fusion of the digital representations may alternatively be a consequence of musician's dystonia.

Epidemiological data have demonstrated a higher risk for those musicians who play instruments requiring a maximum of fine-motor skills. In instruments with different work load for both hands, focal dystonia appears more often in the more heavily used hand. These findings strengthen the assumption that behavioral factors may be involved in the etiology of musician's dystonia (Jabusch et al. 2005). Recent data suggest that hereditary factors may play a greater role than previously assumed. A pilot study of three families associated with three index patients affected by musician's dystonia revealed a total of seven relatives affected by other forms of focal task specific dystonia (Schmidt et al. 2006). These preliminary findings suggest a genetic contribution to focal task specific dystonia with phenotypic variations including musician's dystonia.

At present, the outpatient clinic of the Institute offers medical care for more than 400 musicians suffering from focal dystonia. Treatment options include therapy with Botulinumtoxin (Schuele et al. 2005), other pharmaceutical approaches, retraining therapies and ergonomic modifications at the instrument (Jabusch et al. 2005). Current research projects aim at improving the therapies and further elucidating the neurobiological causes of this disorder.

Auditory sensorimotor integration and music-supported training of motor functions after stroke

Previous studies have shown that only three weeks of piano training can induce neuronal representations of skilled finger movements activated by auditory stimulation (Bangert and Altenmüller 2003; Bangert et al. 2006). This study investigated whether such a cross-modal mechanism for auditory sensorimotor integration can be employed or not in the rehabilitation of motor functions following a stroke (Schneider et al. 2007).

We evaluated a music-supported training program designed to induce auditory sensorimotor co-representation of movements in stroke patients. Patients without any previous musical experience participated in an intensive step-by-step training that began with the paretic extremity and was followed by training of both extremities. Training was applied 15 times over 3 weeks in addition to conventional treatment. Fine as well as gross motor skills were addressed using either a MIDI-piano or electronic drum pads. Other stroke patients undergoing exclusive conventional therapies were recruited as a control group. Behavioral pre- and post-treatment motor functions were monitored using a computerized movement analysis system and an established array of motor tests. To investigate the activity of cortical regions in the control of movement, we studied event-related desynchronization/synchronization (ERD/ERS) and event-related coherences from all patients performing self-paced movements of the right index finger (MIDI-piano) and of the whole arm (drum pads).

Patients displayed significant improvement after training with respect to speed, precision, and smoothness of movements as shown by 3D movement analysis and clinical motor tests. Furthermore, compared to the control patients, motor control in everyday activities improved significantly. Neurophysiological data showed a significantly larger decrease of EEG signal (power) before the time of movement onset in the music-supported training group in the post-training register, which is associated with increased corticospinal excitability, whereas there were almost no differences in the control group. The music-supported training group presented a pronounced enhancement of the coherences after the training compared to the control group, especially in using the drum pads. This innovative therapeutic strategy is an effective approach for the motor skill neuro-rehabilitation of stroke patients.

Outpatient clinic for performing arts medicine

The Institute offers medical care to students of the Hanover University of Music and Drama and also has a special outpatient clinic for musicians with playing-related problems. The clinic specializes in the diagnosis and therapy of musculoskeletal injuries and neurological disorders. Diagnostic equipment is available for measuring nerve conduction velocity, electromyogram, electroencephalogram biomechanical parameters (e.g., key pressure during piano-playing) and motor performance (Jabusch et al. 2004). Services at the clinic are provided by the physicians, Prof. Dr. Altenmüller and Dr. Jabusch. Dr. E. Altenmüller is registered with the German health board.

Staff

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