Strawinskys „Motor Drive“

Monika Woitas und Annette Hartmann (Hg.)

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Inhalt

Innere und äußere Motorik

Monika Woitas und Annette Hartmann

> Ich habe immer einen Abscheu davor gehabt, Musik mit geschlossenen Augen zu hören, also ohne daß das Auge aktiv teilnimmt. Wenn man Musik in ihrem vollen Umfange begreifen will, ist es notwendig, auch die Gesten und Bewegungen des menschlichen Körpers zu sehen, durch die sie hervorgebracht wird.[1]

Die aus diesem Zitat sprechende Vorstellung einer im Körper verankerten Musik und die daraus letztlich resultierende spezifische Qualität von Igor Strawinskys Kompositionen wurde in der Forschung bislang kaum weiter hinterfragt. Dies gilt auch für die Bühnenwerke, obwohl gerade hier Körper und Klang, Musik und Bewegung unmittelbar korrespondieren. Man begnügte sich mit Schlagworten wie „Prinzip Ballett“ oder „Motorik“, um das Wesen dieser Werke zu erfassen. Doch was macht jenen „powerful motor drive“ aus, der George Balanchine[2] zufolge so typisch für Strawinskys Musik ist? Woher stammt diese Faszination für Bewegung und Tanz, die sich so klar in den Kompositionen widerspiegelt und Choreographen unterschiedlichster Stilrichtungen immer wieder magisch angezogen hat? Wie wirkt sich schließlich diese alles durchdringende Motorik auf eine choreographische Gestaltung aus? Und warum fällt Strawinskys radikale Neuformulierung musikalischer Ausdrucksmittel in *Petruschka* (1912) und *Le Sacre du Printemps* (1913) auf einen so fruchtbaren Boden, dass viele Musik- und Tanzhistoriker hier den Beginn der Moderne datieren?

Das seit Oktober 2005 vom Rektorat der Ruhr-Universität Bochum geförderte Forschungsprojekt hat diese (und weitere) Fragen von zwei Seiten her in Angriff genommen: Zum einen sollte die „innere Motorik“ dieser Musik näher definiert werden, zum anderen galt es, die „äußere Motorik“ einer zunehmend kinetisch geprägten Lebenswelt als (notwendigen?) Kontext dieser Neuorientierung zu erkennen und Spuren in den Kompositionen nachzuweisen.

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1 Igor Strawinsky: *Erinnerungen* [Paris 1935-36]. In: *Schriften und Gespräche I*, Mainz 1983, S. 85f.

2 Vgl. George Balanchine: *The dance element in Strawinsky's music*. In: Minna Lederman (Hg.): *Stravinsky in the Theatre*, New York 1949, S. 250-277.

Innere Motorik – sciences & humanities

Seit Mitte der 1990er Jahre haben sich die Neurowissenschaften vermehrt Fragen der Perzeption von Musik und Bewegung gewidmet. Damit eroberten die „sciences" Terrain, das in der Vergangenheit eher den „humanities" zugerechnet wurde. Publikationen wie *Musik im Kopf, Das wohltemperierte Gehirn* oder *Tanz im Kopf*[3] machen bereits im Titel deutlich, dass Phänomene wie Musik und Tanz nunmehr auch aus neurowissenschaftlicher Perspektive zu betrachten sind – was bei einer Vielzahl der betroffenen Geisteswissenschaftler zunächst einmal Irritationen ausgelöst hat. Kunst sollte das bloße Resultat neuronaler Reaktionsmuster sein? Eine Reduktion kreativen Potentials und künstlerischer Produktivität auf Stoffwechselvorgänge im Gehirn – inakzeptabel! Dabei ging es zumindest der Mehrzahl der Neuro- und Kognitionswissenschaftler gar nicht um den hier unterstellten Automatismus. Jeder Künstler kann (und wird wohl auch) von jenen Wahrnehmungsmustern abweichen, die man aus eigener Erfahrung kennt und die von der Psychologie bereits seit geraumer Zeit erforscht werden, die nun jedoch mittels neuer bildgebender Verfahren auch nachweisbar sind. Und warum sollten die hier entdeckten Muster und Vernetzungen nicht auch den kreativen Vorgang beeinflussen?

Komponisten und Choreographen könnte man durchaus als Menschen definieren, die besonders sensibel auf akustische und/oder visuelle Reize reagieren und die Fähigkeit besitzen, diese in Klänge und Bewegungen umzuformen. Ein Komponist transformiert Bilder und Klänge seiner Umgebung in musikalische Strukturen – er wird so (mit den Worten Balanchines) zu einem „Schöpfer von ganz wunderbarer Zeit"[4], in der sich wiederum der Choreograph bewegen kann; denn wo unsereins bei einer mitreißenden Musik nur mitwippt, entwirft dieser neue Raum-Zeit-Gestalten. Die neuronalen Aktivitäten beim Anhören von Musik oder beim Betrachten einer Bewegung geben Hinweise auf Wahrnehmungsmuster, die möglicherweise nicht allein für die Rezeption von Musik und Tanz, sondern auch für deren Produktion relevant sein könnten.

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[3] Manfred Spitzer: *Musik im Kopf. Hören, Musizieren, Verstehen und Erleben im neuronalen Netzwerk*, Stuttgart/New York 2002; Robert Jourdain: *Das wohltemperierte Gehirn. Wie Musik im Kopf entsteht und wirkt* [New York 1997], Berlin 2001; Johannes Birringer/Josephine Fenger (Hg.): *Tanz im Kopf*, Münster 2005.

[4] Interview mit Horst Koegler [Tanzarchiv-Reihe Bd. 1, Köln 1964], zit. nach: Lydia Wolgina/Ulrich Pietzsch (Hg.): *Die Welt des Tanzes in Selbstzeugnissen. 20. Jahrhundert*, Berlin 1977, S. 227-244, hier S. 231.

Strawinskys Kompositionen für die Bühne (und hier vor allem jene für den Tanz) bieten sich als Studienobjekte in besonderer Weise an: Könnten doch die neurowissenschaftlichen Erkenntnisse Hinweise darauf geben, warum gerade diese Musik so oft choreographiert wurde und was ihre Motorik letztlich ausmacht. Im vorliegenden Band werden daher erstmals neurowissenschaftliche mit tanz-, theater- und musikwissenschaftlichen Ansätzen verbunden, wozu Kolleginnen und Kollegen aus allen genannten Bereichen um Beiträge gebeten wurden. Diese Integration von sciences & humanities, in den USA bereits seit einigen Jahren durchaus gängige Praxis, stellt in Europa immer noch eher die Ausnahme dar – zumindest was die Einbeziehung konkreter tanz- und musikwissenschaftlicher Fragestellungen angeht.[5]

Auch für die Neurowissenschaften ist es alles andere als selbstverständlich, dass Forschungen zur Wahrnehmung von Musik einerseits, Tanz andererseits unmittelbar konfrontiert oder gar zusammengeführt werden.[6] So stehen im vorliegenden Band erstmals allgemeine Einführungen zum komplexen System der Spiegelneuronen (**Beatriz Calvo-Merino**) oder zu der im Biomechanik-Labor erforschten Kognition von Tanz (**Bettina Bläsing**) neben Darstellungen, welche die Perzeption von Musik und Rhythmus mit Blick auf Strawinsky erneut hinterfragen (**Michael H. Thaut**) oder für die Vernetzung von Rhythmus, Musik und Bewegung aus der Beschäftigung mit Strawinsky neue Fragestellungen formulieren (**Jessica Phillips-Silver**). Die Auseinandersetzung mit Kompositionen Strawinskys, die weit über die bislang dominierende Verwendung einfacher Beispiele und simpler Rhythmen hinausgeht, wurde dabei von den Autoren durchweg als Desiderat formuliert, von einigen gar als Herausforderung begriffen und gerne angenommen. Im letzten Beitrag dieses Teilkapitels „Zur inneren Motorik" erfolgt schließlich eine erste Konkretisierung, die Strawinskys Musik vor dem Hintergrund neurowissenschaftlicher Erkenntnisse neu zu deuten versucht (**Monika Woitas**).

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[5] Vgl. etwa die 2006 von der VW Stiftung eingerichtete „European Platform for Life Sciences, Mind Sciences, and the Humanities", in der allerdings weder Musik- noch Theater- oder Tanzwissenschaftler zu finden sind.

[6] Vgl. die von Kopiez angemahnten Desiderate der Forschung in: Reinhard Kopiez: *Musikalischer Rhythmus und seine wahrnehmungspsychologischen Grundlagen*. In: Christa Brüstle/Nadia Ghattas/Clemens Risi/Sabine Schouten (Hg.): *Aus dem Takt. Rhythmus in Kunst, Kultur und Natur*, Bielefeld 2005, S. 127-148.

Äußere Motorik – Rhythmen & Lebenswelten

Auch die Integration kulturhistorischer Aspekte in eine musik-, tanz- und theaterwissenschaftliche Fragestellung erscheint naheliegender als dies in realiter meist der Fall ist. Gerade die Hypothese, dass die zunehmend kinetisch geprägte Lebenswelt nach 1900 eine Veränderung nicht nur der Wahrnehmungsmodi, sondern auch der kompositorischen Prinzipien bewirkt hat, ist innerhalb der Musikwissenschaft alles andere als selbstverständlich. Rhythmusforschung erfolgt meist bezogen auf sehr konkrete (rein musikalische) Beispiele und stellt eher selten Bezüge zu kulturellen Kontexten oder gar zur Technikgeschichte her. Dabei dürfte die nach der vorletzten Jahrhundertwende stetig und rasant zunehmende Dynamisierung des Lebens Kunstproduktion und -rezeption nachhaltig geprägt haben. Ein Werk wie *Le Sacre du Printemps* ist eigentlich nur vor dem Hintergrund dieser Veränderungen denkbar: Die vom Komponisten wie von Interpreten und Rezipienten als Einheit von Klang und Körperaktion wahrgenommene Motorik ist eben nicht nur als intuitive Umsetzung neurophysiologischer Anlagen, sondern auch als Reaktion auf jene „äußere Motorik" lesbar, die im Lärm der Metropolen, im Rhythmus der Maschinen sowie der Dynamik neuer Verkehrsmittel und Medien täglich erfahrbar war. Musik als metaphysisch verstandene „tönend bewegte Form"[7], wie sie Eduard Hanslick 1854 deutet, mutiert spätestens im *Sacre* 1913 zur körper- und rhythmusbasierten Klangmaschinerie, deren Schöpfer sich nicht mehr als Genie, sondern als Handwerker oder besser: Konstrukteur begreift, der sein Material auswählt, formt und schließlich in Bewegung setzt.

Die Beiträge des zweiten Teils greifen diese Hypothese auf und verfolgen die vielfältigen Spuren des neuen Lebensgefühls. Die sich verändernde Lebenswelt um 1900 gleicht einem bunten Kaleidoskop, in dem Futurismus und Jugendkult, Vitalismus und Industrialisierung, Varieté und Inszenierungen des Konsums in Warenhäusern und Mode aufeinander treffen (**Joachim Fiebach**). Im Strudel dieser „ästhetischen Beschleunigung", wenn nicht gar in dessen Zentrum, findet sich auch Strawinskys *Le Sacre du Printemps*, den einige Zeitgenossen nicht als vorhistorisches Ritual, sondern als gigantische Rhythmusmaschine wahrgenommen haben – eine Synthese aus Mensch und Maschine („man-machine") und zugleich tönender Spiegel moderner Metropolen (**Barbara Zuber**). Die zunehmende Dyna-

[7] Vgl. Eduard Hanslick: *Vom Musikalisch-Schönen. Ein Beitrag zur Revision der Ästhetik der Tonkunst*, Leipzig 1854.

misierung des Lebens geht einher mit einer Dynamisierung der Musik, wobei es zu einer regelrechten Explosion des Rhythmischen kommt (**Christa Brüstle**). Revue-, Gesellschaftstanz und Reformbewegungen reflektieren diese Entwicklung auf je eigene Weise und prägen so das Lebensgefühl der Zeit (**Annette Hartmann**). Welche Spuren diese durch Metropolen und Maschinenrhythmen veränderte Wahrnehmung in Bühnenwerken Strawinskys hinterlassen hat, fragt schließlich der letzte Beitrag dieses Teils (**Monika Woitas**).

Fallbeispiele

Der dritte Teil widmet sich ausgesuchten Beispielen, an denen die zuvor vorgestellten Ansätze konkretisiert werden. Dabei geht es (noch) nicht um Vollständigkeit oder um den Nachweis, dass die Prinzipien der „inneren und äußeren Motorik" im Œuvre Strawinskys immer und überall gelten. Vielmehr handelt es sich um den Versuch, neurowissenschaftliche bzw. kulturhistorische Erkenntnisse analytisch fruchtbar zu machen – was natürlich die Auswahl der Werke bis zu einem gewissen Grad beeinflusst hat. Von der Transformierung urbaner Klänge in *Petruschka* (**Monika Woitas**) über die Rezeption des *Sacre* als Klangmaschine und dessen choreographische Umsetzungen (**Annette Hartmann**) geht es weiter zur „inneren Motorik" der Sprach- und Bewegungsspiele in *Les Noces* und *Histoire du Soldat* (**Monika Woitas**). Die Identifizierung ‚fremden Materials' in *Apollon Musagète* legt Tiefenschichten der musikalischen Konstruktion offen (**Jörg Rothkamm**), während Strawinsky und Balanchine in *Agon* zu gleichberechtigten Co-Autoren werden (**Stephanie Jordan**), weil sie Tanz und Musik von Beginn an als Einheit denken. Und so spannt sich der Bogen von der noch relativ mimetisch geprägten Adaption großstädtischer Eindrücke bis zur ‚reinen' Konstruktion von Musik und Bewegung, die nurmehr abstrakte Formspiele hervorbringt. Ob dieser Zugriff auch auf andere Bühnenkompositionen Strawinskys (etwa *Oedipus Rex*, *Orpheus* oder *The Rake's Progress*) oder gar andere Komponisten (wie Bach) übertragbar ist, wird die Zukunft zeigen.

Abschließend möchten wir nicht versäumen, all jenen zu danken, ohne deren Unterstützung dieses Buch nicht zustande gekommen wäre. Neben den Autorinnen und Autoren, die sich so engagiert der Auseinandersetzung mit einem für sie teilweise neuen Thema oder zumindest ungewohnten Denkansatz gewidmet haben, gilt unser Dank dem Rektorat der Ruhr-Universität Bochum, das dieses Projekt durch Einrichtung einer eigenen Stelle sowie eine großzügige Anschubfinanzierung überhaupt erst möglich gemacht hat. Dass Sie als Leser dieses Buch nun tatsächlich in Händen halten, wäre allerdings ohne Unterstützung der Andrea von Braun Stiftung München nicht möglich gewesen, die uns zudem durch ihr großes Interesse an interdisziplinären Fragestellungen und persönliche Feedbacks nicht nur finanziell zur Seite stand. Unser Dank gebührt auch der Paul Sacher Stiftung Basel, die den Nachlass Igor Strawinskys beherbergt und so zur Fundgrube für uns wurde. Gleiches gilt für das Tanzarchiv Köln, das uns nicht nur für die Recherche, sondern auch in Fragen des Urheberrechts eine große Hilfe war. Wir danken zudem Stephan Thoss, Johannes Grube und Martin Kaufhold vom Hessischen Staatstheater Wiesbaden für ihr Interesse an unserer Fragestellung und Bereitstellung von Material. Und nicht zuletzt gilt unser Dank Martin Lücke und Sinan Yaman, die uns die Finessen von Layout-Programmen näher brachten, technische Katastrophen jeglicher Art verhinderten und dabei stets die gute Laune bewahrten.

Bochum, im Juli 2009
Monika Woitas und Annette Hartmann

TEIL I

Zur inneren Motorik

Perception of Music and Rhythm
A Neuroscientific Perspective on the Music of Igor Stravinsky

Michael H. Thaut

A neuroscientific review of music perception that centers on the musical works of Igor Stravinsky should start with a brief review of the musical nature of his compositions in order to provide an artistic basis for a survey of brain research in music. I propose that his innovations in musical forms and structures are of particular interest to the modern neuroscience of music and should therefore be brought into a clear focus first so that the scientific discussion of music remains linked to the impact of Stravinsky's works on how we perceive and think of music.

Igor Stravinsky (1892-1971) ranks highly among the most influential and prolific composers of the 20th century. Undoubtedly he will stay with us as a seminal figure in modern music, an innovator and far-reaching musical thinker who moved through very different stylistic phases in his life but in all styles remained true to his own musical language that he developed throughout his life. Although his compositional output is large and encompasses an enormous range of styles and forms, he may be remembered best for two radical changes he brought to existing musical culture. For one, he made composing ballet music a seriously recognized art form. Throughout music history, even still in the 19th century, composing music for dance was always ranked as a secondary skill, usually reserved for the musical 'craftsman' rather than the serious composer. That changed dramatically with Stravinsky's composition for *Firebird* in 1910, commisioned by Diaghilev, director of the Ballets Russes in Paris. *Firebird* was followed in rapid succession by *Petrushka* in 1911 and *Le Sacre du Printemps* (*The Rite of Spring*) in 1913. The latter caused a riot in the audience at its premiere for its revolutionary musical structure and – for that time – highly graphic movement choreographies. These works made Stravinsky world famous within a very short period of time and established him as a leader of the musical avantgarde of his time. He added more 'movement music' later – post world war I – with, e.g., *Pulcinella*, *Les Noces*, and *L'Histoire du Soldat*.[1]

Stravinsky's fascination with dance and his unusual prowess to write for ballet in powerful and revolutionary ways may have been driven by the musical element of rhythm as the single overriding and defining feature of Stravinsky's music from his first to his last works. He expanded and innovated the rhythmic vocabulary and grammar of musical language in unprecedented ways, from the primitive (*Les Noces*) to the sophisticated (*Le Sacre du Printemps*). His rhythmic architecture was new and complex – new metrical structures, shifting accentuations to create synchronous and asychronous vertical rhythm patterns, cross rhythms, irregularly varied pulse groups juxtaposed with common practice metric structures – as a temporal framework to experiment with new melodic and polyphonic vocabularies such as sequences of parallel chords, polychords, or counter points of chords.

Although Stravinsky had no formal dance or movement training and he thought of himself purely as a musical composer his works clearly testify that he had a deep intuitive and incredibly complex grasp on the internal dynamcis and structures of movement as a kinesthetic language, especially in its artistic and expressive forms. He was a revolutionary translator of the architecture of movement and dance into the architecture of music. And his ability to think and conceptualize musical rhythm in new and much more expanded and complex forms gave him enormous freedom within a new musical vocabulary to translate ballet into music in ways of expression and complexity that were entirely new and pathbreaking.[2]

Music processing in the brain

In music, the human brain creates and experiences a unique, time-ordered, and integrated process of perception, cognition, and motor action based on the occurence of streams of sound events. Sound events are organized melodically or polyphonically in different patterns but they require another organizing musical element for their shape and structure. They require rhythm as flow of sounds and silences in time. If we arrest the flow we can

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[1] Cf. Charles M. Joseph: *Stravinsky Inside Out*, New Haven 2001.

[2] Cf. Charles M. Joseph: *Stravinsky and Balanchine. A Journey of Inventions*, New Haven 2002.

only have isolated sounds in space or inanimate notes on notational paper. Therefore, in its broadest definition, rhythm refers to the structured distribution of elements and events in time, a template of ordered and patterned temporal organization. Only in its more narrow definition does rhythm refer to explicit divisions of time or space into intervallic time systems, recurrent and often (but not always) characterized by periodicity. In music, components of the complex language of rhythm include pulses, beats, accents, and meter systems, etc.[3]

Rhythm organizes and structures time. In music as a temporal language of sound and auditory images, rhythm assumes a central syntactical role in organizing musical events into coherent and comprehensible patterns and forms. However, rhythm is also a critical element in motor control and execution, coordination, and learning of movement in all aspects, from the simple and basic to the most complex athletic or artistic endeavors. But rhythm is also recognized as a critical element to drive patterns of meaning in symbolic communication of artworks. Rhythm can determine, assign, and build temporal relationships between events, creating meaning in perception. Rhythm has expressive value in communicating the flow and depths of emotions. It is important to remember the various functions of rhythm as a pervasive, complex, and highly varied phenomenon of temporal order that has such broad-based influence on multiple cognitive, perceptual, and motor functions but also has assumed critical roles in cultural and artistic symbolic communication.[4]

In Stravinsky's ballet music we see a new and deeply interwoven integration of many of the functions of rhythm, in driving motion, translating the organizing elements of movement in time, space, and force into sound patterns, guiding and focusing the attention of the audience, and communicating symbolic meanings in the plot of the choreography and story line.

What can a neuroscience perspective add in important information to a critical discussion of Stravinsky's music for movement? Can musical brain science provide new knowledge that helps understand the profound impact of Stravinsky's music, especially in the area of dance and movement? Our discussion on music and rhythm above offers important points to guide us in our subsequent discussion on music perception and brain function.

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[3] Cf. Gary E. Wittlich (Ed.): *Aspects of 20th Century Music*, Englewood Cliffs NJ 1975.
[4] Cf. Daniel E. Berlyne: *Aesthetics and Psychobiology*, New York 1971.

Brain research in music has seen an unprecedented growth in the past twenty years, mostly driven by new technologies in brain imaging to study the human brain in vivo in complex cognitive and motor functions. One of the most important general insights from this research has been that music is not a single unitary function represented in the brain in a focal manner restricted to a few brain areas that mediate musical functions. Music engages the brain in a broadly distributed fashion across both the left and right hemisphere and also vertically, including higher level cortical as well as subcortical areas. Music obviously engages the auditory system, from the ear through the pathways of the auditory nerve all the way to the auditory cortex in both hemispheres of the brain. Earlier notions in brain research that music is mostly processed in the right hemisphere are certainly not correct. However, in the addition to purely auditory perception areas music also activates many other complex cognitive, perceptual, and motor processing centers in the brain. Just as music is a sound language that consists of many interwoven yet distinguishable components, this complexity and diversity is reflected in the wide array of brain areas necessary to comprehensively process the perception and performance of music.[5]

Returning to the topic of Stravinsky's music for movement, many fascinating details have become known about the intricate relationship between sound and movement and rhythm's influence on the planning, learning, and expressive performance of movement. The special relationship between dance and music has always been recognized artistically and culturally throughout human history. Music inspires and enhances dance, and dance has inspired and stimulated the expression and composition of music. However, little has been known until a few years ago from a neurobiological perspective about this age-old relationship that has been documented throughout human history across all cultures. Until then, any discussion of the relationship and interaction between music and movement could only be conducted on purely behavioral aesthetic, artistic, cultural, or educational levels.

[5] Cf. Giuliano Avanzini/Luisa Lopez/Stefan Koelsch/Maria Majno (Eds.): *The Neurosciences and Music II. From Perception to Performance. Annals of the New York Academy of Sciences*, vol. 1060, New York 2005.

Two landmark studies, one by Paltsev and Elner in 1967[6] and one by Rossignol and Melville Jones in 1976[7] showed for the first time evidence for intricate physiological connections between the auditory and the motor system. Paltsev and Elner showed that sound could amplify the strength of monosynaptic motor reflexes that are controled on the spinal cord level without conscious control of the brain (similar to the well known knee jerk reflex). These findings meant that there had to be a direct link between auditory information processing and motor neurons in the spinal cord. This link was further confirmed by Rossignol and Melville Jones who found reflex amplifications that were so fast that they could not be processed by nerve pathways from the ear to the brain and then down to the neurons on the spinal cord. The transmission had to come from nerve pathways in the brain stem that connect quickly auditory and motor systems below the level of higher perceptual and cognitive processing centers in the brain. Many years later we confirmed this anatomically by testing patients who had interruptions in the auditory pathways leading to the brain due to bilateral stroke. These patients were cortically deaf – consciously they could not hear sound – but their motor reflexes on the spinal cord level responded to sound input with stronger muscle activations.[8]

In a critical next step, Rossignol and Melville Jones also discovered that not only could sound prime and excite the motor system for movement physiologically but that rhythmic music also entrained muscle activations in the leg in time with the musical beat patterns during dancing in anticipatory fashion. These findings – physiological sound timing of movement in addition to sound priming of movement – became the basis for a large new research area investigating the ability of auditory (musical) rhythm to entrain and synchronize movement.

[6] Cf. Yuri I. Paltsev/Anatol M. Elner: *Change in Functional State of the Segmental Apparatus of the Spinal Cord under the Influence of Sound Stimuli and its Role in Voluntary Movement*. In: *Biophysics*. Vol. 12, 1967, pp. 1219-1226.
[7] Cf. Serge Rossignol/Geoffrey Melville Jones: *Audiospinal Influences in Man Studied by the H-Reflex and its Possible Role in Rhythmic Movements Synchronized to Sound*. In: *Electroencephalography and Clinical Neurophysiology*. Vol. 41 no. 1, 1976, pp. 83-92.
[8] Cf. Michael H. Thaut: *Rhythmic, Music, and the Brain*, New York/London 2008.

Music and movement: a brain perspective

The auditory system is extremely sensitive to detecting and analyzing temporal information due to the physical characteristics of the sensory information it processes. The physical bases of sound and music are vibrations patterns in vibrating objects and air molecules. The basic information of pitch, time, durations, timbre, loudness, sound location, and phase relationships between sounds are all extracted from the temporal structure of sound waves. The temporal structures or periodicities are very fast and complex and require a processing system that is equally fast, precise, and extremely sensitive to changes in timing. We can hear minute changes in pitch frequencies or intensity levels of sound based on small changes in the repetition rate or amplitude of a sound wave. Differences in arrival times at the ears of one millisecond or less between two different sound waves help us to locate sound sources in space.[9]

One of the most fascinating discoveries, however, has been how the speed and precision of time processing of sound in the brain can translate into entraining and synchronizing movement via auditory rhythm. Many studies have shown how auditory rhythms become very effective cues for people to coordinate and time their movememts. Tracking a metronome beat with finger tapping feels like a child's game for most, although the actual timing mechanisms beyond the level of conscious awareness are actually quite complex. In our laboratories, we have shown in many studies that people who are asked to synchronize their movements to beat patterns with subtle changes in the tempo of beat patterns – within millisecond ranges that are consciously not audible – will nevertheless follow the time changes with their movements in rapid adaptations in order to maintain exact synchrony.[10] When using brain imaging techniques during such experiments to study the brain mechanisms underlying these rhythmic auditory-motor interactions, we discovered that the strength of the activation patterns of the neuron (neurons = cells in the brain) ensembles in the auditory cortex systematically vary with the duration of the beat intervals: the amplitude of the activation increases with longer and decreases with shorter beat intervals.

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[9] Cf. Richard M. Warren: *Auditory Perception: A New Analysis and Synthesis*, Cambridge 1999.

[10] Cf. Michael H. Thaut/Robert A. Miller/Leopold M. Schauer: *Multiple Synchronization Strategies in Rhythmic Sensorimotor Tasks: Phase vs period Corrections*. In: *Biological Cybernetics*. Vol. 79 no. 3, 1998, pp. 241-250.

Increases in the amplitude of neuronal activation fields require that more neurons fire actively in larger degrees of synchrony with the other neurons in the same network. The picture of an orchestra getting tuned and playing together in increasingly precise timing is an attractive picture to visualize such workings of cell groups in the brain. Longer beat intervals require slightly larger orchestras or neuronal networks to measure time durations.[11] One has to remember that these fast and precise neurophysiological responses in the brain mediate very exact and precise perceptual processes and motor responses which, however, do not reach levels of conscious awareness in the brain. These responses tell us that there are very close and deep neurobiological connections between the auditory and the motor system – between rhythm and movement – serving as the biological basis for the artistic and aesthetic relationship between music and movement.

The relationship between auditory rhythm, music, and movement is actually so strong and powerful that this connection has been found to be very helpful in therapy.[12] In many research studies we and others have discovered that rhythm and music are very effective stimuli to retrain neuromuscular coordination in rehabilitation of movement disorders such as stroke or Parkinson's disease. Music and rhythm as sensory timers of movement can actually compensate for and stabilize dysfunctional processes in the injured brain to help a person with Parkinson's disease walk faster or a person with a stroke to walk with better balance and speed and symmetry between the weak and strong leg. There is a remarkable physiological basis for the fact that auditory rhythms can entrain movement patterns, driving them into the same frequencies as the rhythmic stimulus. The impressive research in such clincial applications – which goes beyond the purely artistic – is another piece of evidence that the relationship between music and movement is innate and a biological constant in the human brain.

In order to study the neuroanatomy of complex musical rhythm perception, we conducted recently a brain imaging study in which professionally trained musicians and persons without any formal musical training were asked to make decisions on discriminating pattern differences in melodic

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[11] Cf. Franca Tecchio/Carlo Salustri/Michael H. Thaut: *Conscious and Preconscious Adaptations to Auditory Rhythmic Stimuli: A Magnetoencephalographic Study of Human Brain Responses*. In: *Experimental Brain Research*. Vol. 135 no. 2, 2000, pp. 222-230.

[12] Cf. Thaut 2008.

and rhythmic elements.[13] We presented to our subjects pairs of different meter, pattern, duration, and tempo patterns, played with a monotone pitch. Furthermore, we compared the rhythmic tasks with a pitch discrimination task where melodies had to be judged in terms of higher pitch contours. The comparison of the neuroanatomical activation areas across all tasks showed surprisingly that all musical elements activated different neural networks. The pitch/melodic contour system was separate from the rhythm perception system in that primarily auditory regions were activated. In addition to auditory areas, each rhythm component showed a different additional neural network subserving the different rhythmic elements. Meter prominently activated inferior frontal gyrus regions in the prefrontal cortex, pattern discrimination was mediated by activations mostly subcortically in midbrain regions, tempo discrimination activated prefrontal areas, and duration judgments activated additional areas in the inferior prefrontal gyrus. Prefrontal areas are broadly active during higher level cognitive tasks such as attention and executive function. All tasks also showed significant involvement of the cerebellum which is a critical brain structure in fine tuning and optimizing the processing of sensory information and motor responses. Considering the sensory and cognitive complexity involved in music perception it would come as no surprise to see strong activations in the cerebellum during musical tasks. In another recent study we actually showed that the only major difference between a simple rhythmic synchronization task as tapping to a steady metronome versus tapping in hemiola patterns (2:3 – 3:2) was the significant increase in cerebellar activation for the much more difficult hemiola task which requires mapping movement performance in complex asymmetric time relationships to an asynchronous metric beat pattern.[14]

One of the most interesting insigts from these studies, however, may be the evidence of the partial separation of brain networks that drive the different rhythm functions. The evidence for such divergent neural network configuration may constitute the neurological basis for the brain to create very different rhythmic languages and vocabularies across musical cultures. One could speculate that without such biological "modularity" built into

[13] Cf. Lawrence M. Parsons/Michael H. Thaut: *Functional Neuroanatomy of the Perception of Musical Rhythm in Musicians and Nonmusicians*. In: *Neuroimage*. Vol. 13 no. 6, 2001, p. 925.

[14] Cf. Michael H.Thaut/Martina Demartin/Jerome N. Sanes: *Brain Networks for Integrative Rhythm Formation*. In: *PLoS ONE* (Public Libray of Science). Vol. 3 no. 5, 2008, p. e2312.

the musical brain all musical cultures would be constrained to the same rhythmic language. As we discussed earlier, that is clearly not the case. Rhythm is a very complex system of time organization and not only have different cultures codified very different rhythm systems in music but rhythmic styles and systems have also evolved and fundamentally changed within a given musical culture over time.

The impact of Stravinsky's music: final thoughts from the neurobiology of music

These findings may bring us back to Stravinsky and our original question what musical neuroscience can bring in new knowledge to an understanding of Stravinsky's music for movement. There are several fascinating answers to consider.

For one, we may see in his ballet music a new exploration of integrating musical and kinesthetic language at the intersection of neurobiology and art. His music engages in new artistic language the fundamental connections between movement and sound and rhythm. We may call his ballet music experimental discoveries – expressed in artistic language – about the biology of music, movement, and the brain. Just as Johann Sebastian Bach's Opus *The Well-Tempered Clavier* was a grand scientific-artistic experiment – facilitated by a new tuning system – of exploring untouched musical territory and building a new musical architecture by modulating further away from original keys signatures than ever before and making it safely back without violating or losing the coherence of harmonic structure, so maybe we can call Stravinsky a discoverer of a new way of fusing two artistic languages that have profound proximity in the neurobiology of the human brain.

Lastly, in Stravinsky's compositions for ballet, rhythm and movement have become an interwoven joint language where movement is translated into rhythmic sound and rhythmic sound drives the expression of movement. We now know that the complexity and diversity of the brain architecture for musical rhythm may be the basis for the free development of diverse rhythmic languages in human musical cultures. Stravinsky's music shows a fascinating example how such diversity can be harnessed for new explorations into translating movement imagery into auditory (musical) imagery of pitch and time.

Mirrors in the Brain as Connection to the World

Beatriz Calvo-Merino

Introduction: the importance of seeing others

Human interaction is an essential part of society. In our culture, interacting with other people is as much a necessity as it is a pleasure, but without it our lives would be empty and futile. The complexity of human interaction has fascinated a different number of scientific disciplines over the centuries, including philosophers, psychologists, sociologists and anthropologists. A key component of social interaction is observing others' behaviour, and humans have developed the extraordinary ability to understand others' thoughts or intentions just by observing their actions, by just looking at their movements. Imagine, for example, a cup of tea on a table. If I observe you reaching towards the cup of tea, I probably understand that you are going to take a sip from that cup. If, however, I see you looking at your watch, then reaching the cup, I may conclude that you are going to clean up the table, or that you are preparing to leave. Overall, we all perform an endless number of such interpretations about others' actions every day. This could overwhelm our mind if it were not realised in an automatic and non-conscious way. The human brain has been shaped by evolution to spend its resources economically, and action observation and understanding is a perfect example how complex and essential processes can occur almost effortlessly.

But how our brain achieves this remains largely undetermined. It has been a long-standing challenge to study how the human mind interprets the actions of others. The discovery of the so-called mirror neurons (MN) was the starting point for understanding social understanding. These mirror neurons have become a major research focus because they open a window into the neural clockwork that allows us to understand other individuals. They provide the evidence that individuals can understand other's people actions by a process of internal simulation of the observed action, or in other words, by simulating *how it feels to do as the other person does*. It has been said that mirror neurons are to psychology and our understanding of the human mind what DNA was to biology.[1] This is a big statement and only time will judge the relevance of this type of brain cells. Either way, consi-dering that mirror neurons were only discovered about fifteen years ago, their discovery has already greatly advanced our understanding about action observation and social interactions.

Mirror neurons are one example of how neuroscience can provide novel insights and empirical evidence about how our brain enables complex social interactions. One of the most common approaches in cognitive neuroscience is to decompose a complex phenomenon (such as social interaction) into simpler and measureable components. The level of reduction sometimes is extraordinary and can barely resemble the initial general question. Nevertheless it is necessary for an exhaustive and clear collection of evidence that later on, will be put together jointly with other small pieces to regenerate and explain the initial general and global concept of interest.

Music research is a clear example; in order to understand how we listen and recognize sophisticated synphonies, researches have investigated for years the simple auditory processing of tones and frequencies.[2] Larry Parsons and his colleagues moved forward and investigated the neural mechanism of dancing to music, by measuring brain activity of tango dancers performing simple tango steps while listening to the correspondent music.[3] Similarly, mirror neurons were first discovered while investigating simple movements such as grasping and reaching in the primate macaque monkey. From here to understand social understanding of complex actions in humans there is a bridge full of speculation, supporting data and evidence. Moreover, the arrival of non-invasive neuroimaging and neurostimulation techniques has provided the appropriate support for this aim. For example, Transcranial Magnetic Stimulation (TMS) provided the first neurophysiological evidence of a mirror system in humans, and studies using

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[1] Cf. Vilayanur S. Ramachandran: *Mirror Neurons and imitation learning as the driving force behind "the great leap forward" in human evolution*. The Third Culture, Edge, 2000. http://www.edge.org/3rd_culture/ramachandran/ramachandran_p1.html, 12. 6. 2009.

[2] Cf. Daniel J. Levitin/Anna K. Tirovolas: *Current advances in the cognitive neuroscience of music*. In: Michael B. Miller/Alan Kingstone (Eds.): *Annals of the New York Academy of Sciences*. Vol. 1156, 2009, pp. 211-231.

[3] Cf. Steven Brown/Lawrence M. Parsons: *The Neuroscience of Dance*. In: *Scientific American Magazine*. Vol. 164 no. 7, 2008, pp. 32-37; Steven Brown/Michael J. Martinez/Lawrence M. Parsons: *The neural basis of human dance*. In: *Cerebral Cortex*. Vol. 16 no. 8, 2006, pp. 1157-1167.

functional magnetic resonance (fMRI) were essential to locate and describe the properties of the mirror mechanism in the human brain.

Nowadays the scientific community widely accepts the existence of a dedicated system in the human brain that enables us to understand observed actions by internally simulation what others do. Here we will review early studies on the mirror neurons system, as well as new perspectives toward the complexity of the MN function, and its role into different ways of seeing movement, such as aesthetic perception, music production, emotion recognition or empathy.

A mirror neuron system in the primate brain

In the early nineties, a group of researchers lead by Prof. Giacomo Rizzolatti in a laboratory in Parma (Italy) made a remarkable discovery that has had a broad impact in the scientific community over the last years. Rizzolatti and his colleagues researched how the brain of the macaque monkey responds during action execution, focussing on an area called F5 in the premotor cortex. This is a part of the motor system known for its participation in planning, selecting, and executing actions. The so-called motor neurons in this area participate directly in the execution of a motor act. They are directly related to the chain of events that eventually triggers our muscles and produces movement. During their experiments, Rizzolatti and his group noticed that there were a set of these motor neurons in the premotor cortex that were not only firing (a common term to indicate a neuron is activated, or involved in a task) during the execution of a determinate movement, but also during the observation of the same movement performed by the experimenter. For many years philosophers and scientists have underestimated the role of the motor system. Motor regions were considered solely and exclusively to the execution of actions, and not much related to the rest of the cognitive human mind, or at least lacking of any observable evidence or data to justify the opposite. Rizzolatti's discovery suggested for the first time that our system for performing movements participates not only in doing but also in seeing what others were doing.

This initial enthusiasm was followed by a large series of control experiments and studies, in order to understand further the properties and possible function of these neurons. These studies suggested clearly that the same neurons were used for both executing an action and watching the same action performed by someone else.[4] Neurons with these properties (motor and visual) were called *mirror neurons* because they seemed to reflect like a mirror an observed action onto our own motor repertoire. Therefore, motor neurons might represent the missing link between action and perception, and their existence suggests that during observation of others' actions we internally simulate their actions within our own action system. Neurons with mirror properties were described in other areas of the macaque brain, such as the parietal lobe.[5] This region is in charge of many functions including transforming information from the visual domain to another sensorimotor.

In total, about 20% of the neurons in the primate area F5 are mirror neurons (i.e., they have visual and motor responses), while the other 80% of neurons have more or less purely motor functions. It is important to emphasise that we do not necessarily simulate the observed action by using our entire motor system, but that a significant proportion of it transmits the information to further levels. Using as classification criteria the level of congruency between the executed and observed motor act that activate each neuron, all mirror neurons have been classified in two groups, namely highly congruency and low congruency neurons. The former participate when the observed and executed action is identical in terms of the movement goal (e.g. grasp a cup) and how the goal is achieved (e.g. grasp the cup with a precision grip). The latter refers to neurons that are less strict and also fire during observation of similar actions. These two types of neurons are necessary to built up a representational map on the observed action in several levels, from purely motoric aspects to abstract levels of intentions. Overall, premotor and parietal regions form a fronto-parietal network for mirroring actions, also called mirror neurons system (MNS), which resonate the observed action in the one we have in our own system.

The immediate question is why these group of neurons fire during both action execution and observation. Is there any physical or functional advantage for sharing visual and motor information in the same neurons? Would

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[4] Cf. Guiseppe Di Pellegrino/Luciano Fadiga/Leonardo Fogassi/Vittorio Gallese/Giacomo Rizzolatti: *Understanding motor events: a neurophysiological study*. In: *Experimental Brain Research*. Vol. 91 no. 1, 1992, pp. 176-180; Vitorio Gallese/Luciano Fadiga/Leornardo Fogassi/Giacomo Rizzolatti: *Action recognition in the premotor cortex*. In: *Brain*. Vol. 119 no. 2, 1996, pp. 593-609.

[5] Cf. Leonardo Fogassi/Pier F. Ferrari/Benno Gesierich/Stefano Rozzi/Fabian Chersi/Giacomo Rizzolatti: *Parietal lobe: from action organization to intention understanding*. In: *Science*. Vol. 308 no. 5722, 2005, pp. 662-667.