The Fluid and the Crystalline – Processes of the Music Performing and Perceiving Body

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Abstract. In music performance the perceptions of musician and audience are fluid and depend on shared embodiment and cognitive processes. This article explores skill development and the stabilisation of expertise through practise, and the corporeal as well as the neural mechanisms at work in music performance and perception. Key questions centre around the affective, embodied but also neurological aspects of this domain. The types of awareness on a corporeal level and the neural processes that occur within the musician and the listener-viewer are investigated. The aim is to show that 'enactive', embodied concepts merely provide a different perspective of the same complex matter than what the cognitive neurosciences propose. The insights arising from blending the two fields can be productive both for artistic practice as well as systematic research in music. A concrete musical piece that exposes an improvising gestural practice using sensor-based instruments and digital sound processing serves as an example to show the problematic relationship between musician, instrument, technology and the audience.

Keywords: embodiment, cognitive sciences, neural plasticity, skill, expertise, stabilisation, gestural, improvised, electronic music, performance

1 Introduction

In this article we look at how the perceptions of musician and audience are fluid and shift depending on shared processes of embodiment and how they stabilise through practise. This is particularly the case in unusual music performance styles involving technical body sensing, extended instruments and digital sound generation. Its co-performative basis in body-perception can be traced to evolutionary, cultural, and social assets that transcend the mere music making situation. Here, these issues are approached by looking at the characteristics of embodied, situated cognition, at intentionality and agency, and the affordances in handling and recognising non-standard musical instrumental actions. A particular emphasis is given to the question what stabilisation processes operate

in rehearsal and performance situations both for performers and audience. The underlying question is how we use the concept of gesture and corporeality to understand affective, embodied but also formal and structural aspects of music performance and perception. The foundation for this inquiry is provided by the 'enactive' [45] and embodied perspective, that can stem both from an experiential and performative perspective and from an empirical, formalised approach represented by the cognitive neurosciences.

In order to ground this reflection in musical practice, the development process over time and the performance of the gestural electronic work entitled 'new islands' provides a concrete example. This contextualisation should make evident the situation both musicians and audience engage in with regard to non-traditional performance practices. With the aid of this use-case we also hope to show some principles that need to be paid attention to in the composition, development and design of musical performance that involve body-sensing and extended or abstracted instruments.

2 Background

Musical processes are manifested as chains of musical actions by performers and as a flow of perceptions on a multitude of levels by the listener-viewer.[4] The shared physical presence during a performance of music, in fact of any music 'consumption', is embedded in the flow of time. Contrary to other art forms, in music our being in time [19] becomes central. "Things take time" to unfold, in particular in the sensory medium of sound, but also in the embodied state and "environmental situatedness" of the musical performance. "We experience a kind of empathy for the performer, an awareness of physicality and an understanding of the effort required to create music. ... In improvisational music, this embodied empathy extends to an awareness of the performers coincident physical and mental exertion, of their in-the-moment (i.e., in-time) process of creative activity and interactivity." [20] The nature of this process is that of a dynamic flow, not simply of time, but of elements constituted of bodily actions that produce distinct sound impressions. This indicates that within musical perception the processes we are affected by, perceive and act out are made by dynamic chains of sound-objects as well as action/sound pairs or multi-modal 'gestural sonorous objects' [18]. These elements form "segregated streams and objects that lead, via the subjective sensing of the subject's body motion, to impressions of movement, gesture, tensions, and release of tension." [26] As musicians perform, they construct a temporal unfolding stream of movement dynamics which the listener-viewer re-enacts and co-performs through kinaesthetic, corporeal resonances and higher order dynamic sensing that is more akin to *moving* oneself than to *sounding* within oneself. The effect of a performance is that it is *indeed*

[4] Throughout this article the audience member, i.e., the person who partakes in a music performance, is always denoted as 'listener-viewer'. We believe that this type of music listening never occurs with the auditory sense alone but always includes the – sometimes inner – eye and above all the corporeal kinaesthetic sense.

the body which constitutes music perception on both the embodied, corporeal level as well as in the social sphere: "Music exists at the intersection of organised sounds with our sensorimotor apparatus, our bodies, our brains, our cultural values and practices, music-historical conventions, our prior experiences, and a host of other social and cultural factors. Consequently, musical motion is really experienced by us, albeit via our imaginative structuring of sounds." [22, p. 255] These processes generate an "aware[ness] of a sense of mutual embodiment. This sense brings about the presupposition of shared time between the listener and the performer."[20] However, the affective impact of the performance, i.e. the effectiveness of the music, within this 'shared time', is not immediately given but arises as the performance unfolds.

How does the musician establish a shared process of temporal, corporeal, movement-and-sound shaping, when neither the tools or instruments, nor the idiom and style conform to a sufficient degree with culturally established norms? Being able to negotiate the flux and the instability of the performance moment demands that the musician prepare and train, which is hard enough with traditional instruments and musical styles, and presents particular challenges when the task includes exploring gestural instruments and abstract sound processes. The musical actions that constitute 'the music' might be prescribed by a 'score' or other instructions, or might be indeterminate, yet culturally or stylistically informed, for example through a shared improvisational practice. With non-traditional instruments and sound processes, learning as well as performing depend to a large degree on the models and methods used, since music is fundamentally shaped by the tools, the desired aesthetic outcome and the context within which it is enacted. This question exposes the underlying issues of 'musicking' [44], which we will only be able to address here in a cursory manner; they exceed the scope of this article and the context within which we are locating this discussion. Our focus will be to draw on the 'enactive' and neuroscientific fields to further the understanding of those processes that occur within the practising and performing musician as well as the partaking listener-viewer.

3 Enactive, Embodied, and Situated Cognition in Music Performance

Let us look at the body and how perceiving and performing relate to musical actions. This is particularly important in the relationship with musical instruments, which represent the single most mediating factor in terms of corporeality for a musician. It is a truism that a musical live-performance involves physical presence of the musician. What is less obvious is that awareness of bodily states plays a central role in constituting the relational or affective power of such a performance. The difference between novice and expert lies in the amount of training, the depth of integrating and imprinting of the many levels of musical and perceptual activities that are necessary to perform music fluently and with ease. In training, the musician experiences over and over again, as practise and rehearsal, the actions that produce a desired sound. The repetitive nature of

practising coordinated movements of instrumental play has the function of establishing body-schemata, "integral kinaesthetic structures" [28] (quoted in [43]), dynamic patterns, or so-called 'kinetic melodies'. However, the thus obtained "knowledgeability is not simply a know-*how*, a lesser of form of knowledge that is 'merely physical.' Kinetic melodies are saturated in cognitive and affective acuities that both anchor invariants and color and individualize the manner in which any particular melody [pattern] is run off."[43, p 256] Through the practising process the embodied 'know-how' becomes pre-reflective and can later, in the right environment and circumstances, be triggered as a unit without the necessity to individually deal with the actions that constitute it. The body accumulates knowledge of movements, dynamics and forces, and in the case of a traditional musical instruments also links it to the perception and the adaptation and control of sound-qualities, thus dealing with movement-sound conjunctions rather than with movement and sound separately. This embodied knowledge encompasses the full range of the body's motion and audition control. It is completely interdependent with the environmental situation, within which it was learned or acquired. Music performance in concert provides one such situation that brings a concept into sharper focus, which Varela et al. have stated in more general terms: "By using the term *embodied* we mean to highlight two points: first that cognition depends upon the kinds of experience that come from having a body with various sensorimotor capacities, and second, that these individual sensorimotor capacities are themselves embedded in a more encompassing biological, psychological, and cultural context. By using the term *action* we mean to emphasize ... that sensory and motor processes, perception and action, are fundamentally inseparable in lived cognition. ... the enactive approach consists of two points: (1) perception consists in perceptually guided actions and (2) cognitive structures emerge from recurrent sensorimotor patterns that enable action to be perceptually guided." [45, p. 173]

3.1 Affordances and the Role of the Instrument

What does the instrument offer to the musician in parallel or in addition to the production of sound? 'Affordances' are what Gibson [17] defined as the ecological potential, as that which an object or environment is offering in terms of actions or resources. He derives the concept from 'Gestalt' psychology's terms of valence, invitation and demand, but he emphasises ecological embedding. "An affordance points two ways, to the environment and to the observer. ... this is only to reemphasize that exteroception is accompanied by proprioception – that to perceive the world is to coperceive oneself. ... The awareness of the world and of one's complementary relations to the world are not separable." [17, p. 141] More recent research ties valence and arousal to the constitution of emotions and memory [23], and *indeed* within the ecological perspective these dimensions play a role as well.

For the musician the awareness of the instrument happens through an *object* perception. Even though the instrument might only be peripherally perceived, while the focus lies for example on the sound or the music, nevertheless this

"object perception involves an experience that is *directed at* the object. The relation at stake here is ... an intentional relation." [14, p. 56] When the musician shifts the attention from sound to sound production, the intentional focus moves from an outer perception of sound to an object perception of the instrument. In both types of attention the instrument is peripherally present and the awareness can at any time be moved onto this object. "Attention can be directed either proprioceptively or exteroceptively, and it can be ... viewed as an alteration of the balance between focal and peripheral awareness. ... Even when the attention is fixed firmly on the ... dimension of tactile awareness, the exteroception dimension remains ... in background awareness." [1, p. 139] The instrument, the musical content or even the body may move to the periphery of the perceptual field or obtain focal attention as a 'perceptual object'. In contrast, we perceive our bodies through an inner sense called proprioception and the kinaesthetic sense. We may become consciously aware of our body as an object, but "it is also possible that proprioceptive awareness can function as a non-perceptual or non-observational self-awareness ... and as such might be regarded as a more immediate and more reliable form of awareness than object perception." [14, p. 54]

3.2 Corporeal Awareness, Agency and Intentionality

Apart from this body-object duality there exist also various types of awareness *within* the body. On the lowest level operate the neurological/physiological mechanisms of proprioception and the somatic, kinaesthetic sense [3]. At this level, a large number of bodily signals are present and form a system that permits an automatic control of posture, locomotion, and physical actions adapted to specific tasks [15]. Somatic and proprioceptive awareness can take both a reflective and a pre-reflective form. If "the first element of broad self-consciousness that somatic proprioception provides is an awareness of the limits of the body" [1, p. 149], then for the instrumentalist the physical contact with the instrument provides a pre-reflective self-awareness that is informed by the instrument, constitutes an element of the sense of agency, and generates a clear context for the bodily awareness [16]. The intentional, object-related actions that are part of playing the instrument build upon this pre-noetic knowledge without necessarily bringing the body into conscious focus. At the next level a fully focused attention on the body may exist. Once the musician, through instrumental training, has achieved a fusion between body and instrument in the domain of the body-schema, the perception can become be observational and constitute a body-image. Above that level the body is only indirectly involved, since the musician needs to deal with musical awareness. The auditive attention of the perception guides expressive aspects of the performance through a different feedback loop than the somatic ones: "the body-image retreats into the background in order to enable the concentration on the sonic-expressive shaping of the entire piece of music." [24, p.111; authors' translation]

In a complementary view on the body, Legrand proposes four corporeal states: the *invisible body* is the body that is absent from experience, the *opaque body* is the object of an observational body experience; the *transparent body* is

experienced only 'as one looks through it to the world' and the *performative body* is based directly on a pre-reflective experience of the body [25]. The latter two modes manage well to represent the situation of the performing musician and anchor the performance experience *at the same time*. The continuous adaptation occurs through the *performative body*, in the first person perspective; the observational awareness and attention is framed by the *transparent body*. Through the corporeal state of the performative body and in an explicit awareness mode the concept of 'performativity' implies that the sense of agency becomes an indispensable element that is constitutive of the experience: "This performative awareness that I have of my body is tied to my embodied capabilities for movement and action. ... my knowledge of what I can do ... is *in my body*, not in a reflective or intellectual attitude" [15, p. 74].

The sense of agency, that is "of oneself as the agent of action" or the fact "that when I'm aware of my actions and experience them as mine, I thereby experience myself: an experience of myself as agent." [29, p. 50] are constituting the self-awareness, which is necessary to perceive and maintain a musical performance. Intentions and control represent the core cognitive aspects of musical actions, in particular on devices and processes that can potentially produce sound without any input or intention from the performer. Neurologically speaking, the bidirectional afferent and efferent streams of information are continuously compared and integrated in the lower regions of the brain and produce a regulatory feedback that forms part of our awareness of actions. "To the extent that consciousness enters into the ongoing production of action, and contributes to the production of further action, *even if significant aspects of this production take place non-consciously*, our actions are intentional." [15, p.238]

4 Musical Performance and Cognitive Neuroscience

Let us now move from the body's senses and sensory streams to the processes they set in action or are based on within the brain. Musical perception and performance have been a subject in neuroscience for almost two decades and are recognised as "one of the most complex and demanding cognitive challenges that the human mind can undertake." [47] This research encompasses the wide fields of creativity and artistic processes (for a review, see [39]). Insights gained from specific brain functioning in these practices lead to advanced models of general brain functioning, which are organised in distributed, overlapping networks, and further the understanding of neuroplasticity [46]. This is particularly relevant since musical performance is integrating perception, attention, cognition, and intentional movement in real-time on all used modalities as well as activating the brain in a highly-specific manner that enables heightened experience and cognitive functions. Musical expertise serves as a model of general expertise gain and intermodal transfer, a model that contributes to understanding how these exceptional brain states critically contribute to enhanced perception and performance as well as to their sustainability [21].

In the following we discuss in what way these principles apply to actual musical performance. We look at the question how expertise and stabilisation emerge on the time scale of the individual's entire life span, the individual's situative, i.e., musical skill acquisition, and we also look at these processes within the time span of an artistic development process (for example of a new piece) and within the time frame of a single performance. Furthermore, the communicational and interpersonal domain is also taken into account. In doing so, the evolutionary processes and neurobiology of music, gesture and motion as well as the individual trajectories of the (artist's) lifespan pave the way to a (neuro-) phenomenological understanding of the artistic process. In view of these aspects, a critical viewpoint is cultivated where the relevance and added value for musical performance (-education) is verified continuously.

4.1 Evolving Motion

The emergence of modern man is tightly linked to a cultural (r)evolution that produced language, music, arts, and eventually complex social systems. Respective changes in brain morphology and functioning move along these evolutionary lines [10]. Motion, always intimately tied to perception, is a common principle of these emerging cultural traits, since the integration of perception, the volitional initiation and sequencing of concrete actions is necessary in each of these cultural domains. In general it is assumed that the human evolution which surpassed our primate ancestors' most prominently manifests itself in those brain regions responsible for planning and sequencing, but also for integrating stimuli with higher cognitive systems [35]. The main brain regions contributing to these skills are found in the most prominently evolving frontal areas of the neocortex. Through a functioning mirror/echo neuron system, which is partly located in theses areas, we are capable of following the movement of others [36], or in the sense of 'enaction' [45] literally embody the perceived actions at the neural level. Interestingly enough, the activated neural systems are also involved in action planning, sequencing, and initiation, which leads to a neurological 'mirroring' of action that may be lacking its bodily execution. By extension these systems comprise brain regions relevant to language (e.g., Broca's Area) that link motion with semantic, communicative or even abstract context [35]. In further support of this perspective, recent neuroscientific studies provide evidence that hard-wired connections between motor cortices, visual, auditory, and language regions exist and are prone to neuroplasticity triggered by training (for a review, see [46]). When put into context, this evolutionary trajectory provides insights into the status quo of poly-modal, or with respect to motion, a unified modality of general brain functioning. This framework provides the neurobiological foundations that facilitate the integration, processing and acquisition of 'motion' sequences in any domain.

4.2 Lifespan Expertise

Recent neuroscience marks a transition from models of a static brain after juvenile development to neuroplasticity across the entire life span [32]. Despite this paradigm shift towards a more 'fluid' perspective on brain development, there are critical phases in each individual's development trajectory, during which learning and performance in certain domains are more effective and sustainable. According to the *last in–first out* hypothesis of neural development [38], the (pre)frontal cortex plays a central role as it matures in late childhood and is subject to atrophy later in adulthood. This leaves the middle adulthood as the phase with the most 'mature' frontal cortex; here the optimisations of expertise and related executive functions converge as the individual profits from expertise acquired during childhood. Within or after the teenage years neural or synaptic 'pruning' occurs naturally and 'limits' the neural learning and dynamic networking capacities. This marks the neurological transition between 'fluid' states of learning and 'crystalline' states of expertise. Nonetheless, there is considerable inter-individual variability in this transition since through specific behaviour the process can be prolonged, slowed down or individually modified to fit one's needs. This neuroplastic 'good news', besides being a classic model of and for musical expertise, is also transferable to ageing, because brain structure and function can be stabilised, conserved or even improved into old age with respective training [46].

A parallel expression of these developmental trajectories with a focus on cognition can be seen in the model of '*fluid*' and '*crystallised*' intelligence [6] (and provides the inspiring eponym to this article). This model theorises, on a cognitive level, that it is possibly related to the neural underpinnings, how expertise is generated in a 'fluid' phase early in life. This then serves as a foundation to 'crystallised' expertise that exhibits an enhanced ability for inter-domain transfers later in life. The transition is gradual and organised individually, and marks the perceived shift of a roaming, all-absorbing young mind to an 'all-knowing' adult mind. The evolution from one state to the other can be recognised in how embodiment [45], perceptual modes [25] or kinaesthetic melodies [28] are established. The key concept is that fluid intelligence primarily makes use of enhanced learning and thus sensory memory functions, whereas crystallised intelligence primarily applies accumulated experience and advanced reasoning.

4.3 The Musician's State of the Brain

Let us leave the background of phylo- and ontogenetic development to focus on actual brain and cognitive functions in 'practised' expertise in musical performance. This context poses one of the most complex sensorimotor challenges to the brain [47]. It requires the integration of sensory (mostly auditory, visual and kinaesthetic) inputs with motor outputs in real-time. It is therefore not surprising that extensive training and acquired expertise are necessary for the performer to execute his skills with ease and to allow her to perform creatively beyond strictly learned schemata. Before going into these neural and cognitive

mechanisms, let us examine the specific 'states of the brain' of a highly skilled musician.

Compared to non-musicians or musical laypeople, on a coarse neuroanatomical level, musicians usually exhibit: 1. A larger and denser corpus callosum connecting the two brain hemispheres, which is developed during the critical phase of juvenile training increasing interhemispheric connectivity and communication [42] 2. A larger auditory cortex as well as a specific inter-hemispheric asymmetry 3. A larger and more dense motor cortex, especially in somatotopic representation of the respective extremities (e.g., areas representing fingers in piano players) 4. Changes in the cerebellum (responsible for motor control, integration and simulation) 5. Increased hard-wired connections between auditory and (pre-) motor areas via fibre bundles (e.g., arcuate fasciculus) [46]. Taken together, extensive training followed by expertise – as they are reflected in their neuroplastic correlates – represents the underlying cause for the structural differences between experts and non-experts. In the light of evolutionary and developmental processes, as well as current knowledge about the 'state of the brain', the heightened interconnectedness between temporal regions (auditory perception and probably also auditory memory), parietal regions (object integration, spatial aspects), and frontal regions (motor sequencing, language) – e.g. via the arcuate fasciculus – points to the fact that auditive musical perception and motor-controlled musical performance are *indivisible*. This fact was already introduced earlier and proves again to be of special interest: some of these regions (i.e., mainly the frontal and parietal areas) are part of the mirror/echo neuron system, which expands the frame of reference to include perceptive and communicational aspects. Based on these neurological differences, musicians furthermore exhibit exceptional executive functions such as attention, working memory, emotional control, planning and reasoning, over and beyond the normal lifespan [21]. Finally, integrating the enhanced polymodal connectivity within the brain, it becomes conceivable that musicians are also capable of more efficiently coding and retrieving memories: In analogy to databases and/or internet search engines they are capable of storing memories with multiple 'tags' which allows them to more rapidly and successfully retrieve information from their memory systems.

Due to their fundamental connections and functions, as well as to the co-evolution and -development, the described neural systems ease the way to domain-specific and possibly general learning, skills and expertise. Moreover it becomes conceivable that performing is superior to 'passive' listening to music – be it in the specific brain regions or the entire brain. Even compared to other expertise demands in sports or visual arts, musical performance seems to be exceptionally 'demanding' as it activates more modalities and cognitive efforts. By applying gestural control, expression and dance within enriched acoustical and visual environments, non-traditional musical performance may provide highly relevant use-cases that push the neurocognitive envelope.

4.4 Movement Expertise

How is (movement-) expertise achieved and how does it affect brain functioning and related cognitive and motor performance? Surprisingly, there seems to be a discernible trend towards less activation within less modalities the further the training process of any expertise evolves [8, 4]. What also resonates within this observation is a trend towards more stability and more invariability, which could be partly explained by the specific tuning and wiring on the level of single neurons, thus minimising (neural) noise production and susceptibility. The transitions through the phases of expertise acquisition are gradual and described as occurring mostly step-wise, as laid out in an exemplary manner in the encompassing review by Debarnot and colleagues [8]:

In a first phase, the sequential motor control is acquired and rehearsed by applying the whole sensorimotor loop of the brain. The mirror/echo neurons are then possibly supporting and the kinaesthetic, visual and acoustic modalities are certainly helping along if the situation demands it. This phase is fundamental and crucial and can only be eased through the acquisition of extensive prior expertise (i.e., in adulthood or after very long training). A 'motor-memory' is built up in subcortical regions and gradually decoupled from cortical – thus 'conscious' – control and guidance, in what Gallagher [15] calls the establishment of body schemata or Sheets-Johnstone [43] calls kinaesthetic memory (see 3.2).

The next step is the goal-oriented mental simulation of the movement, i.e. 'motor imagery' that permits the individual to 'imagine' a movement without actually executing corporeal motion. Throughout these processes, reduced but more specific goal-oriented neural activity is introduced (see for example golf practice [4]) and at this point the 'expert' usually has achieved a sufficient skill set. This can be observed in expert sportsmen as well as musicians in their ability to silently rehearse and prepare a performance.

Transcending this level is the decoupled and abstract level of 'meditation', where no prior motor rehearsal or training is necessary. This can be regarded as an example of transfer between domains, and as a meta-level of conceptual understanding and integration, as the performer becomes capable of 'pure' mental movement and unconstrained, freely flowing creative actions.

4.5 Movement and Gesture Communication

After describing relevant processes of expertise and stability gain in a musical (and other artistic) performance within an individual person, let us expand the frame to the inter-individual domain. As introduced above, mirror/echo neurons with their respective automated imitation processes are key in these reasonings [35][36]. It was shown that these specialised neural assemblies are not only activated during observation of goal and object-directed hand movements, the *same* sites get activated while observing communicative or expressive hand gestures [30], and body referring manual actions [27]. This implies an automatism of gestural communicative coding by the individual, which is based on the underlying principle of motion (-imitation). In a follow-up experiment, it was shown that

when comparing the perception of social hand gestures with facial expressions, the activation pattern differed [31]. The condition of facial expression recognition and imitation activated the frontal part, whereas recognition of hand gestures showed larger activation in the posterior regions. This goes in line with the observation and intuition about the perception of gestures and general expression in a musical performance: Facial expression seems not to be necessarily linked to gestures in the rest of the body and tends to convey emotional content more directly.

Besides the automatic perception and integration of basic motion, semantics and emotions, the respective brain mechanisms seem to extend to the aspect of intention [5][13][11] or even identification [9]. Perspective taking, recognition of intentions and to a certain extent empathy [2], are usually subsumed under the term 'theory of mind' [11]. In the context of music performance, H.L. Gallagher [12] showed differential cortical activation when comparing instrumental and expressive gestures. The perception of expressive gestures activated the brain regions associated with the 'social brain' while instrumental gestures activated preferably left-lateralised areas associated with language and (motion-) imitation. As a further step in the transition to applying neuroscientific findings to musical performance contexts, a concrete example in the form of a 'neuro'-informed dance/movement therapy (D/MT) is of particular interest [2]. Simply put, D/MT makes use of the automatically activated systems of imitation and empathy in therapeutical settings, where the mirror/echo neurons are used to override acquired emotional and social barriers in immediate, unfiltered corporeal experience.

In summary, there are no specific theories or studies available yet, that investigate these 'mirrored' perceptions and actions, when it comes to their evolution and stabilisation over time. This makes it impossible to infer mechanisms that would be involved in action or perception – in general and particularly in specific musical performance such as our use-case(s) – only from evolutionary, developmental or momentary neuroscientific data, since longitudinal or time-variant research is still missing. The evidentiary basis of our argument is therefore reduced to the adoption of insights gained from a wider view than those *in the moment temporal aspects* of brain functioning and cognitive mechanisms.

At this point the problem of diverging concepts, methodologies, and data becomes imminent [39]. The limits and future challenges of this approach are summarised by Decety and Chaminade in the following manner: "... the mechanisms involved in intersubjectivity cannot be reduced to this common mapping, neither at the neurophysiological level nor at the cognitive level. This system is interwoven with self-consciousness, as well as with the phenomenological experience of agency. Thus one highly relevant issue, both in neuropsychology but also from an evolutionary perspective, concerns how the self-versus-other distinction operates within these shared representations and which neural mechanisms are engaged in integrating and discriminating the representations activated by the self and those that are activated by external agents." [9] This shared neural representation model highlights the self-other distinction, consciousness of self, the

experience of agency, and emphasises the inter-subjective nature of, in this case, music performance.

5 Performance Practice of Gestural Electronic Music

After all the groundwork in perceptual psychology and the cognitive neurosciences, we are finally capable of looking at a specific model of musical performance with gestural interfaces and electronic sound-processes.

As shown above (see 3.2), in almost all musical situations, the combination of body potential and instrumental affordances provides a driving duality. This is particularly the case in a technological music practice, such as sensor-based electronic music, where instrumental actions cease to be exclusively perceptually guided, that is, not exclusively given by the physics of the instrument's acoustics, and where cognitive structures emerge that are informed less by *perceptually guided* actions than by *conceptually structured* perceptions. These mental processes are common in the playing of notated music, but the way that gesture, sound-production and musical structure are interdependent becomes more specific in electronic music performance and with digital musical instruments.

5.1 Empty Handed Play

The practice of performing with empty hands and physically with sensor-instruments has a history in the field of electronic music. Musicians such as Michel Waiszfisz, Laetita Sonami, Atau Tanaka have been exploring this practice for decades. A convincing performer of this type of gestural music was Michel Waisvisz[5], in particular because the integration of his instrument on a body-image level was clearly discernible. The mixture between instrumental control and physical movement, combined with direct treatment of vocal sounds, generated an expressive performance that in our opinion appealed on the physical, corporeal as well as on the musical level.

A work from our own practice shall serve as a springboard to elucidate the connections established in the two preceding sections. The piece *'new islands'* was premiered in 2011 and has been in ongoing development ever since, with one or two performances per year.[6] The guiding principle for this composition is to explore sensor-based, gestural actions with empty-handed gestures, controlled with the aid of sensor-gloves and cameras, or with a symbolic sensor-instrument that restitutes the object character of an instrument without providing actual sound generation [40]. The current version of the piece concentrates on performing with a pair of sensor-gloves and a wireless headset microphone. The piece can be regarded as a composition insofar as the real-time sound-processing is

[5] Videos can be found online (URL accessed 05/2015):
`http://steim.org/2009/10/remembering-mw/`
`https://www.youtube.com/watch?v=U1L-mVGqug4` .

[6] For a collection of videos documenting the evolution of this piece please see:
`http://www.jasch.ch/island.html` (URL accessed 05/2015)

highly structured and stable, but it could arguably also be regarded as a hybrid instrument encompassing the gloves, and their mapping to the digital sound processing. Currently there are no prerecorded materials, all the sounds are captured in real-time through the microphone during the performance itself. The structure of the actions, the intended performance energy and the resulting forms are (re-)created every time, and have evolved on some levels, while in order respects have remained stable.

The evolution of the piece and the way it 'feels' to the musician during performance provides a relevant connection to both the 'enactive' and the neuroscientific perspectives. The insights and reflections gained about the corporeal states inform on a fundamental level how the piece is structured. In order to leverage the skills and expertise of the performer and at the same time leave enough space for an exploratory attitude, key aspects or principles of the 'composition' such as stability of mapping [41], keeping manageable the size of the mental map of sound-processes, and an independence from visual representation need to be respected.

It is precisely through these processes that the four temporal frames of expertise and experiential stabilisation we established earlier can be observed. The experience over time by the musician of how the mental map of the piece evolves and the attitude in the playing of this piece changes indicates that a settling or crystallisation process has occurred. This long term solidification happens to a lesser degree for the audience as well: throughout the performance, the principles, actions and ways the sounds and actions are correlated are first perceived, then learned, and then recognised. The analogous process within the duration of a single performance is based on cultural and social assets [34], but also on fundamental corporeal inter-subjective identifications [33] and is necessary to produce affective impact [37]. For the performer, thanks to the stable elements in the composition his or her body remembers how it *feels* to gesture with these sound processes. For the performer, the sensor-mapping and the mental map necessary to navigate the 'instrument' or 'piece' appear to have become imprinted – at least to some extent – and the corporeal impulses for certain gestures or movements during the performance start to resemble those that occur on a traditional instrument. For the listener-viewer who has witnessed *several* of these performances, the noticeable difference in the quality of performance – even if not specifically identifiable – indicates a similar settling; the situation becomes familiar and the expected actions and sounds fall within a known field of possibilities. This familiarity comes from the stable and recurring parts of the 'composition' and the unchanged stage situation that remains frontal. It must only be relativised when the character of the piece changes from one performance to another, due to evolving artistic concepts used for the 'narrative' aspects of the work.

As mentioned, the effect of this stabilisation also influences the perceptual integration of elements for the audience. One of the listener-viewers who witnessed the first as well as the most recent performance of the piece provides this personal account of the experience: "I was able to let go and dwell in the web

of linguistic, emotional, philosophical and perspective-changing 'synaesthesia' of the piece. The grains of sound were grains of discovery - within the stretched phrase all possibilities seemed to be conveyed but not accessible to the conscious mind. It gave me all the time I needed to discover and visit that island."

6 In Conclusion

This reflection on processes in the music performing and perceiving body is supported by insights from the partial overlap with two neighbouring fields of perceptual psychology and cognitive neuroscience.

The primacy of movement is a foundation of our evolutionary development and corporeality, it underpins all human activities and in particular musical performance and perception. In order to understand the complex layering of our embodied, situated and cognitive performance, we propose to consider the dynamics of flow, and the continuous exposure and adaptation as the *key element* which enable skill stabilisation and the formation of expertise. The issue we approach here is how to transfer between, or how to stabilise within the domains, the multiple and intertwined modalities and the skills involved in music performance in particular, and in any complex corporeal activity in general. The resonances and imitation systems detailed in the mirror neuron theories find their equivalence in the complementarity of the performer-listener pair, where many of the mental and corporeal processes and cognitive mechanism occurs in mirrored constellations.

Having reviewed the mechanisms of expertise gain, we must re-emphasise the influence of emotions and motivation for the performer. The intrinsic motivation through joy and fun arise from recognition by an audience but also from mastering the challenges of the performance situation. From a neurological point of view, these intrinsic psychological enhancers are not directly involved in the processes described above, but rather boost the individual's performances and experiences. Intrinsic motivations are determining aspects for reinforcing learning and gain in expertise by providing arousal (basal and reactive), valence (personal and salient) and emotions [23]. The additional effects provided by these psychological factors are not merely key to improving the expertise development processes, the added value is also to be found in the personal fulfilment and success of the performance.

The embodied awareness and neural processes in the musician and the listener-viewer are interdepedent states, which we can represent through the *metaphors* of the '*fluid*' and the '*crystalline*'. In all the temporal frames we looked at, i.e., the life-long development span, the individual's formative training phase, the artistic development process for a singular work, and the timespan of a single performance, we can observe recurring patterns that oscillate between the two polarities. The flow-states [7] reached during performance, as well as within the process of musical training, are contributing factors to the stabilisation of skills and expertise. Well established skills in turn also facilitate unconstrained creative actions. These states seem to be present in all three of

the expertise building modes: when activating 'motor-memory', when generating 'motor imagination' and even in states of free 'meditation' [8]. Finally, as an essential effect of the stabilisation of skills through increased expertise, they are freeing up the performer by providing sub-personal and cognitive resources that may be mobilised in order to better explore and shape the dynamic flow of a musical performance.

With this article we attempt to bridge the gap between cognitive neuroscience and perceptual psychology from the vantage point of the musician, particularly from a reflective position that draws on these neighbouring fields. The neuroscience point of view – even if apparently only dealing with the brain – complements the embodied, 'enactive' perspective. From this standpoint it seems that the two fields are merely two perspectives of the same complex matter, that spans across embodied awareness, neurological processes and beyond. Cognitive sciences have indeed moved away from computational models of cognition and have begun to embrace the fact that there is no separation between brain and body, and that cognition involves the entire corporeal sphere. What phenomenology and psychological philosophy have established is now shown by the cognitive neurosciences: in perception and cognition brain and body fuse, and this unity extends to the ecological perspective.

Music performance provides a rich terrain within which to explore these connections. By exposing the musician and the audience to atypical and creative re-combinations in the gestural performance of electronic sound, the junctions, ruptures and fusions inherent to this field are revealed even more clearly.

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