A Music Module in Working Memory? Evidence from the Performance of a Prodigious Musical Savant

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A music module in working memory? Evidence from the performance of a prodigious musical savant

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• **ABSTRACT**

This article investigates the possible existence and nature of a "music module" in working memory after Baddeley (1986) and Berz (1995). Evidence is gleaned from the performance of a prodigious musical savant in hearing and playing back an unfamiliar piece. His ability to realise internalised auditory images of considerable complexity on the keyboard with immediacy and an unusual technical facility offers a rare opportunity to glean something of the workings of the musical mind in a direct and ecologically valid way — through purely *musical* responses. These are subject to an initial musicological analysis using "zygonic" theory (Ockelford, 2005a, 2005b), which seeks to explain how the structure and content of the savant's output is derived from the stimulus and from other sources, and how both are woven into a coherent musical whole. The underlying methodological assumption is that the perceived sonic relationships so identified offer powerful evidence of processes that are hypothesised to underlie the learning, storage and retrieval of musical elements in cognition.

INTRODUCTION

This article explores and develops William Berz's (1995) notion of a "music module" in working memory which, he suggests, may function alongside the other more or less discrete systems (notably the "phonological loop" and "visuo-spatial sketchpad") postulated by Alan Baddeley (1986). Following Atkinson and Shiffrin (1968), Baddeley considered these systems to be supervised and controlled by a "central executive", together making up a tripartite model as shown in Figure 1.

The existence of additional "slave" systems was implicit in Baddeley's general concept of working memory and, indeed, he and Pierre Salamé explicitly opened the door to the possibility of a music module in their discussion of the (weak) effect of background instrumental music on phonological short-term memory. They concluded that "the fact we can hear and remember sounds that are very unlike

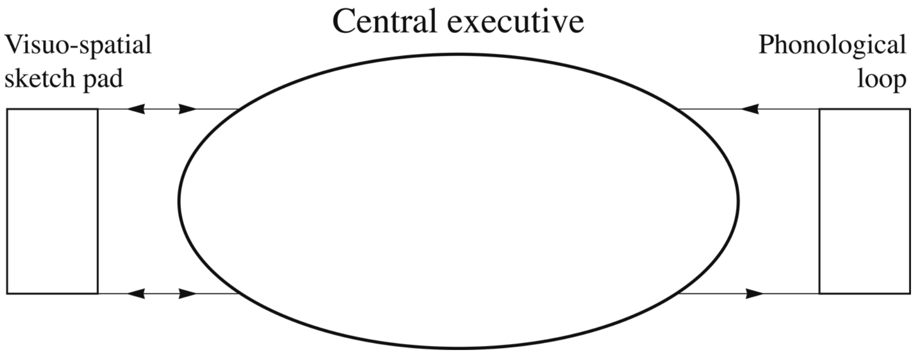

Figure 1.
"A simplified representation of the working memory model" (after Baddeley, 1997, p. 52).

speech means that there must be some — presumably additional — form of storage system capable of dealing with such material" (1989, p. 121). In addition to this study, Berz (*op. cit.*, pp. 360 and 361) cites the findings from a number of other reports to support his proposition, including the dissimilar relationships between modality and recency effects in language and music (for example, Roberts, 1986), suggesting that the two are encoded differently, and the differing degrees of disruption caused by language and music in a variety of experimental storage tasks.

Inevitably, though, Berz's hypothesis raises more questions than it answers. He asserts, for example, (based on his review of previous work) that a music module, if such exists, must have the capacity not only for storing information in the short term, but also for encoding it based on organisational factors or schemata. But is this likely to be a sufficient description of the processing capacity of the music module, or are there perhaps other features that are not captured in Berz's (admittedly initial) account? If so, how might these functions engage with one another? Could their interaction be managed by the central executive, or is it reasonable to suppose that there might be a dedicated, domain-specific control mechanism *within* the music module itself? That is, is can we assume that the music module is in reality a composite of yet-to-be-specified sub-modules, which are themselves organised in hierarchical fashion? Berz further presumes that music schemata formulated in working memory must somehow relate to similar structures held in long-term memory, though the nature of this relationship remains undetermined. Evidently, this is an area ripe for further investigation.

The "remus" project

Such an opportunity recently presented itself through the "REMUS" [1] Project — a joint initiative of the Royal National Institute of the Blind, London, the Psychology Department of Goldsmiths College and the School of Arts and Humanities at the Institute of Education, University of London. [2] The project focuses on the abilities of musical "savants": people with exceptional skill in the context of learning disabilities (see, for example, Rimland and Fein, 1988; Howe, 1989; Miller, 1989, 1998; Treffert, 1989, 2000; Ockelford, 2000; Hermelin, 2001). The project comprises a series of studies that aim to glean new insights into the nature of savants' musical ability, in particular learning, memory, reproduction and creativity, and to use these findings to generate models of the processes involved, adopting a fusion of music-psychological and music-theoretical approaches (*cf.* Cross, 1998; Gjerdingen, 1999). The underlying methodological assumption is that savants' performance in terms of the musical pieces and fragments that they produce following exposure to controlled musical input — specifically, the extent to which their responses can be considered to derive from the stimuli with which they are presented and the nature of such derivation — provide powerful evidence of the cognitive processes involved. [3] That is, the research assumes (and will hopefully demonstrate) that it is reasonable to deduce the latter from the former. In the longer term, it is intended that the findings of the REMUS Project should be used to underpin new didactic approaches in working with savants (and others), inform the wider debate on the nature of musical abilities in general and stimulate further research.

Derek Paravicini

One of the REMUS performance studies in particular yielded data that, it appeared to the researchers, may usefully bear on our understanding of working memory and music. This involved Derek Paravicini, who was 25 years old when the research commenced. He had been born premature at just 25 weeks gestation, with a birthweight of 0.65 kg. As a result of the oxygen therapy required to keep him alive, Paravicini had developed "retinopathy of prematurity" (see, for example, Fielder and Reynolds, 2001) which had irreversibly damaged his retinas and left him with only

(1) That is, "Researching Exceptional MUsical Skill".

(2) Led by the current author, Director of Education at the Royal National Institute for Blind People and Visiting Research Fellow at the Institute of Education, Linda Pring, Professor of Psychology at Goldsmiths College, and Graham Welch, Professor of Music Education at the Institute of Education.

(3) *Cf.* John Sloboda (2005, vi and vii), who writes of the "core psychological tradition, where overt human behaviour is the central form of data, and explanatory frameworks are developed in primarily intentional and functional terms".

the perception of light in one eye. It soon became apparent that his intellectual functioning was affected too, and during his school career Paravicini was classified as having "severe learning difficulties" (Ockelford, 1991) — implying that his progress in cognitive, emotional and social terms was in the early stages (as in the first twelve to thirty months of usual development; see Welch, Ockelford and Zimmermann, 2001, p. 9). At the time of the research, Paravicini's verbal IQ was 58 measured on the WAIS-R (UK version) — although this result needs treating with caution since inevitably the procedures employed were not entirely standard. In any case, it is evident that many of the building blocks of everyday understanding, such as "cause and effect", "same" and "different", and "left and right", are beyond Paravicini's conceptual grasp, and he needs one-to-one assistance in undertaking day-to-day activities such as getting dressed and preparing meals.

As soon as Paravicini's fingers sense a music keyboard beneath them, however, all their infantile gaucherie evaporates to be replaced with an extraordinary dexterity. Indeed, an unusual technical facility was already in evidence when the author first encountered Paravicini at the age of five. Then, his typically frenetic playing would generate a kaleidoscope of sounds, in which the main melodies of pieces were barely discernible amidst cascades of elaborate if somewhat chaotic passagework. Songs from the shows, TV theme tunes, nursery rhymes, folksongs *et cetera* were all transformed through the addition of rapid figuration, largely produced with an "off-the-key" finger technique, resulting in a somewhat percussive style of playing that is still characteristic of Paravicini today.

With systematic weekly and then daily teaching over a period of five years, Paravicini flourished, and just before his tenth birthday he performed with the Royal Philharmonic Pops Orchestra at London's Barbican Centre, an event that launched a flurry of international media interest. But this initial success was tenuous, and the crucial next step for those working with Paravicini was to ensure that he made the difficult transition to a musically-fulfilled adulthood, in which his learning disabilities would tend to work *against* rather than *for* him (as they had done hitherto) in terms of public perception: when his talents would be valued in their own right rather than through the lens of a misplaced if well-meaning curiosity. Pursuing this aim meant hundreds of hours more of concentrated effort (which Paravicini enthusiastically embraced): consolidating technique, extending an already eclectic repertoire, introducing a range of performers and styles to encourage the development of a new and distinctive musical "voice", and refining social and communication skills so that these were not a hindrance to music-making with others — for socially-based musical activity was becoming more and more a central feature of Paravicini's self-identity (*cf.* MacDonald, Hargreaves & Miell, 2002). To achieve this he had to be capable of a high level of conformance: playing what was required and when, and in an agreed key, tempo and style![4] Hence, without

(4) Paravicini must be the only 9 year old ever to be rebuked for starting *Yesterday* in F♯ major (rather than F), much to the consternation of some of his fellow musicians during a concert!

subduing his natural predilection for doing things in his own way,[5] Paravicini also had to accept the importance of copying exactly what he heard, and of performing pieces in the *same* way several times over when necessary — between rehearsals and a concert, for example, or for re-takes during the making of a film. In the event, such routine came to appeal to Paravicini as much as his improvisatory forays.

An unanticipated though welcome side-effect of Paravicini's potential for disciplined performance has been his capacity for participating in music-psychological research. Here is someone who, as faithfully as he can, will reproduce on the keyboard whatever he is hearing or has heard, and will willingly make further attempts on the same or subsequent occasions. Here is a subject who will modify his reproductions as requested (playing a piece in different keys or tempi, for example), and will improvise on materials that are presented in a range of styles. Here is a musician whose ability to play by ear is so accomplished, and whose responses have such an immediacy, that one senses a rare opportunity to glean something of the workings of the musical mind in a direct and ecologically valid way (*cf.* Clarke, 2005) — through purely *musical* responses to music.

THE CHALLENGE OF STUDYING MUSICAL MEMORY

With most people — musicians and non-musicians alike — the challenge of studying musical memory is that subjects simply cannot reproduce in sound the auditory images that a range of evidence suggests they have stored in some cognitive form. That is, in terms of musical communication, their receptive skills are far more advanced than their capacity for expression. Hence, the great majority of research into musical memory has taken a *metamusical* tack, requiring listeners to make judgements such as "the same" or "different" *about* the music they have heard (see, for instance, Dowling, Tillman & Ayers, 2001).[6] It goes without saying that such methodologies have proved enormously valuable in gaining evidence as to the nature of musical memory. However, they have had inevitable limitations too. For example, the mapping between words and musical experiences is notoriously imprecise, making this a treacherous territory for researchers. Even everyday labels such as "the same" or "similar" are potentially subject to overextension in musical contexts, meaning significantly different things to different people in different circumstances: see, for instance, Cook's (1994) critique of Wolpert (1990); also Ockelford's (2004)

(5) The extent and nature of Paravicini's musical creativity is to be the subject of a separate publication (Ockelford, forthcoming).

(6) Notable exceptions include Sloboda's investigation of the immediate recall of vocal melodies (1985) and Melissa Knecht's study of music expertise and memory among novice and professional violists (2003) — though in both cases the musical materials that were used comprised only melodic fragments.

commentary on Lamont and Dibben (2001). Then, because "real" music is so complex, with a great many variables, it may never be possible to build up a "bigger picture" of musical memory by using only tiny fragments of information that are gleaned indirectly. To put the matter simply: if challenged as to how much we currently know about a person's memory of a piece that she or he has just heard, we would have to say "very little". So a fruitful next step, it would seem, would be to find a way of glimpsing the bigger picture of musical memory — imperfect as this view may be — and then to use other approaches, including no doubt metamusical ones, to fill in some of the details.

Here is where research with savants such as Paravicini may have an important role to play. Self-evidently he *can* realise in sound many of the auditory images that he holds in his head. Of course, even with his extraordinary facility for playing by ear, we would still expect there to be a difference between what he can process and what he can perform (the "receptive/expressive gap"), but nonetheless he is able to offer direct musical evidence of his thinking in a way that is far beyond the capacity of most people. That is to say, although we should not expect his playing to offer a complete reflection of his mental images of music, a rich though partial source of first-hand data seems preferable to none at all.

This is not to downplay the methodological difficulties that do exist, however. For example, there are a number of ways in which the very process of producing sounds may affect the veracity with which auditory memory traces are realised. Indeed, the memories themselves may become corrupted through imperfect reproduction, and this important issue of interference at a cognitive level will be discussed in a future publication (Ockelford, forthcoming). Here it is worth noting the potential impact of the physical constraints of performance on the responses that subjects make This was exemplified in a preliminary study of the REMUS Project, in which two savants and a control musician were presented with a "disembedding" task (*cf.* Heaton, 2003) in which they were asked to replay on a keyboard as accurately as they could chords and clusters comprising 4 to 9 notes that had been created with a digital piano sound.[7] The results are shown in Figure 2.

Here, "DP" refers to "Derek Paravicini", "AJ" to a second savant who also had exceptional aural abilities, and was principally a percussionist with some keyboard skills, and "SE" to a control, who was an accomplished jazz pianist and therefore used to playing by ear. It was previously ascertained that all three participants had a refined and universal sense of "absolute pitch". With regard to AJ, it is evident from video recordings of the session that he found his limited facility on the keyboard a considerable impediment. Particularly with aggregations comprising 7 notes or more, he was perceptibly struggling to get his fingers over the appropriate notes in order to recreate the pitches that he could evidently hear in his head; and as the

(7) There were twenty examples in each condition.

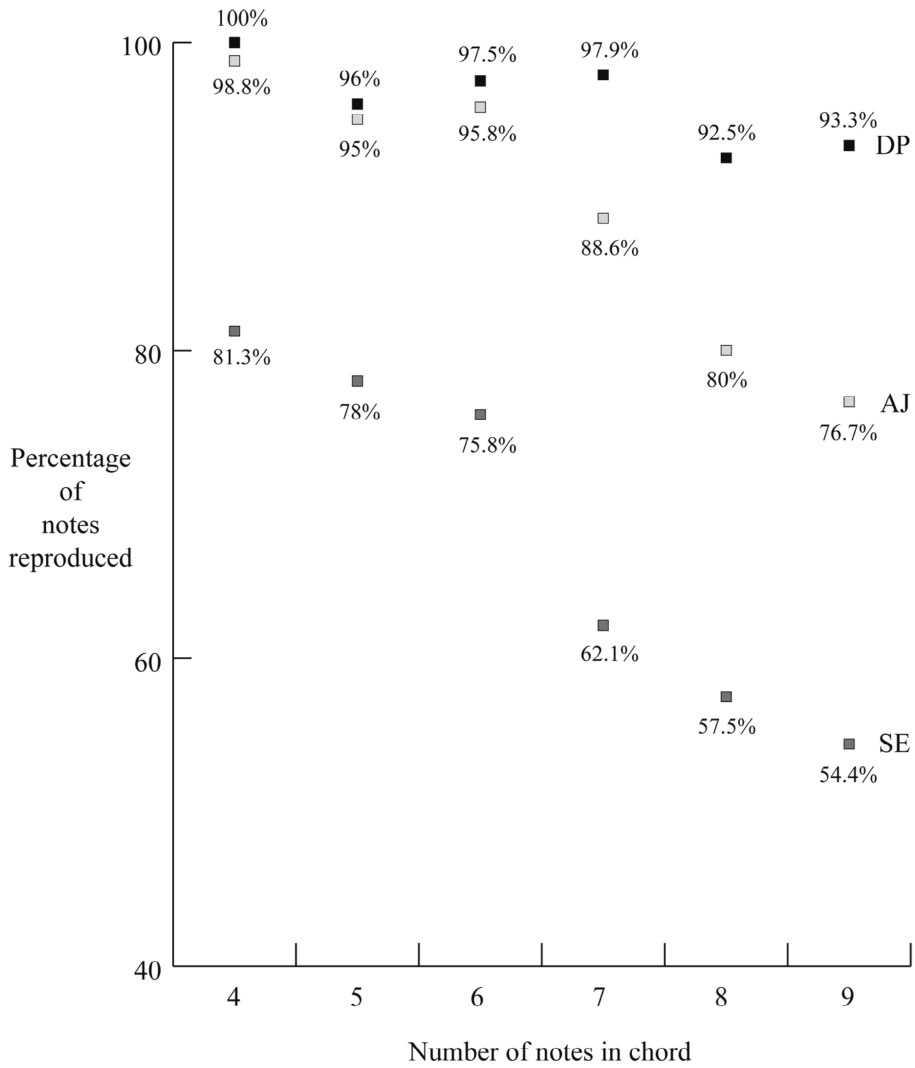

Figure 2.
Results of chordal disembedding task for two savants and a control.

chords grew larger he was increasingly frustrated through running out of time[8] before his digital manoeuvres were complete. Hence AJ's results, particularly those pertaining to 7, 8 and 9-note chords, may well understate the extent of his perceptual abilities and short-term memory. With SE, the main issue appeared to be the

(8) There was a ten-second interval between each stimulus.

possibility of his striking the correct notes purely by chance, since the combinations of (say) 9 notes within (for example) a two-octave range that can be played simultaneously are limited.[9] Hence there is a danger, due to the physical design of the experiment, that SE's results may *over*state his auditory-processing capacity.[10] With DP, since there was little deterioration in accuracy with even 9-note chords, the potential problem is that the number of pitches he can hear at the same time is likely to exceed his complement of fingers! Were the experiment to be extended, therefore, to even larger aggregations of notes, his performance would inevitably be *under*stated. Clearly, the approach to data gathering could be changed to circumvent some of these issues (by allowing respondents to play the notes successively,[11] for example, and by providing more time between stimuli). They are mentioned here as being indicative of the type of challenges one is likely to encounter using the "listen and play" method of research (*cf.* Miller, 1989, pp. 27ff).

A potentially more serious criticism though that could be levelled at the use of savants' performance data to study memory is the extent to which people such as Paravicini, with exceptional levels of domain-specific expertise, may process and remember things in a fundamentally different way from most other people. If this were the case then, of course, the findings from savant studies would have little if any general applicability. And, indeed, the results of experiments such as that reported above do suggest that certain of Paravicini's abilities, such as disaggregating chords and recognising pitches, may be highly untypical — even of other expert musicians. So at the very least, we may surmise that Paravicini's musical memories are unusually rich, reflecting his abnormally detailed auditory landscape. However, there is no evidence to suggest that the global architecture of Paravicini's music storage and retrieval systems differs *structurally* from that of most other people. On the contrary, preliminary analysis of the performance of a comparison subject who took part in the experiment described below in the same way as Paravicini hints at similar cognitive processes at work: a limited short-term system of memory and recall which prioritises events of particular salience (including through primacy and recency effects), with the capability, characteristic of expert performance, to chunk materials according to underlying structure (see, for example, Knecht, 2003), and with the

(9) To give a feeling for the probabilities involved, the chance of *not* striking a correct note at all in these circumstances is around 1 in a 1,000.

(10) The experiment was subsequently re-run for the *60 Minutes* programme (screened in the US on 23rd October 2005) with a different control whose results were similar to SE's, and who was asked, in addition, to provide a commentary on her efforts. She was clear that she found the larger chords, containing clusters of tightly-packed notes difficult to "hear", and she adopted the approach of first locating the top and bottom pitches and then filling in those between with a certain amount of informed guesswork. This was in contrast to DP who always responded without hesitation, irrespective of the size or complexity of the chord involved.

(11) In any case, Paravicini's responses were often arpeggiated rapidly from bottom to top.

capacity to stimulate traces of musical features and fragments of other pieces held in a long-term store — the two caches coordinated through some form of central control system. Where differences do exist, these appear to be of degree rather than kind. What is indisputable, however, is that this area merits further research and that, for now, the one should be cautious in seeking to generalise too much from the results reported below.

THE "LISTEN AND PLAY" EXPERIMENT

The "listen and play" experiment was the first extended piece of research undertaken with Paravicini in the REMUS Project, and an initial overview is given in Ockelford and Pring (2005). The experiment was one of four designed to capture just how Paravicini learns pieces and were based upon the ways in which the researchers had observed him operate. The four conditions, all designed to take place over a number of sessions were "listen and play" (described here), "just listen" (in which an unfamiliar piece is heard on several occasions before the first performance is attempted), "play along" (in which listening and performance occur simultaneously) and "a bit at a time" (in which the successive fragments of the new material are heard and copied).[12] The studies had three aims which are of relevance here: to record in detail Paravicini's efforts at reproducing the pieces in each condition; to analyse this information and to use the results to build a model of how he memorises music (in both the short and long term); and to reflect on what these findings may tell us about musical learning and memory in general.

The "listen and play" study entailed Paravicini learning a piece by listening to it on a number of separate occasions, each time attempting to play what he could remember once he had heard the music in its entirety. A piece was especially composed for the experiment and given a name that Paravicini would find memorable: the *Chromatic Blues* (see Figure 3). It was important to create new material because it was difficult to find pieces that one could safely assume Paravicini had not heard before. The following criteria informed its composition:

1. The style (equating, in music-theoretical terms, to general features such as the relative pitch and temporal frameworks used and the transition probabilities between successive events) should be broadly familiar to Paravicini.

(12) The most similar study reported in the literature was that by Sloboda, Hermelin and O'Connor (1985) in which a prodigious savant (NP) and a professional pianist both attempted to learn portions of Grieg's *Melodie*, Op. 47, no. 3, and the "Whole-Tone Scale" piece from Bartók's *Mikrokosmos*, Book 5, through hearing and playing back sections at a time. They concluded that NP's exceptional abilities for memorisation were confined to tonal music and were structurally based, supporting the view that general intelligence is not a pre-requisite for structure-based skill. These findings are supported by the current study with DP which looks in detail at what "structure-based" music memorisation and reproduction entail.

2. There should, in addition, be specific features that were unusual within the style, offering higher degrees of salience.
3. The piece should be of sufficient difficulty to be found challenging, though possible for Paravicini to learn after a number of hearings, given its length and complexity (in music-theoretical terms, determined by characteristics such as the ratio of chromaticism to diatonicism and the number of notes appearing simultaneously).
4. Technically it should be relatively undemanding, so that considerations of performance difficulty should not interfere with issues of music-processing.

Chromatic Blues

Figure 3.
The Chromatic Blues*.*

Chromatic Blues was recorded digitally by the author using a Korg SP-200 88 note touch-sensitive hammer-action keyboard linked to a laptop computer, monitored through Edirol MA-10A speakers. The accuracy of the rendition was verified through the production of a further score using "Finale" MIDI-based notation software.

Statistically, the piece comprises 312 events that occur within 49 seconds. Structurally, it may be represented as follows (see Figure 4).

segment	$A_{1.1}$	$B_{1.1}$	$A_{2.1}$	$B_{2.2}$	C
function	Theme A – exposition	Theme B – exposition	Theme A – reprise	Theme B – transposed, extended	Coda
tonal regions	I → (V of ii)	♭VII → V	I → (V of ii)	♭III → V	I
range (beat.bar)	0.4 – 4.3	4.4 – 8.3	8.4 – 12.3	12.4 – 18.3	18.4 – 20.4

Figure 4.
Form of and general statistics pertaining to the Chromatic Blues.

The "listen and play" experiment with Paravicini was conducted over 13 sessions. The first 10 had been planned to occur twice a week, spaced as equally as possible, for five weeks, followed by gaps of 3, 6 and 12 months. In the event, other commitments (and Paravicini's own preferences) meant that this pattern could not be adhered to consistently, and the time intervals that actually occurred between sessions are shown in Figure 5. The entire data-gathering process took place over a period of approximately two years.

Following the first session, every other went as follows.

1. Paravicini was asked to play the *Chromatic Blues* as well as he could using the keyboard on which the piece was recorded, in a quiet room with no distractions, and the results were recorded using a MIDI system. He was thanked, but with no evaluative comment.
2. He was asked to listen carefully to the recording of the original *Chromatic Blues.*
3. He was asked to play *Chromatic Blues* for a second time as well as he could, followed, again, by thanks but no evaluation.
4. He was asked to listen carefully to the recording of *Chromatic Blues* once more.

In Session 1, the first step was omitted.

It is on this initial session that we will focus our attention in the remainder of this paper,[13] building up a phenomenological account of Paravicini's first attempt at playing *Chromatic Blues* ("Rendition 1"), having heard the original once through

(13) A great deal of other data was gathered from the subsequent sessions, much of which is of potential interest; this will be discussed in Ockelford (forthcoming).

Session number	*Trials*	*Days since previous session*	
1	1	–	
2	2 & 3	2	
3	4 & 5	5	≈ 2 weeks
4	6 & 7	2	
5	8 & 9	7	
6	10 & 11	25	≈ 1 month
7	12 & 13	2	
8	14 & 15	5	= 2 weeks
9	16 & 17	2	
10	18	5	
11	19 & 20	96	≈ 3 months, 1 week
12	21 & 22	198	≈ 6 months, 2 weeks
13	23 & 24	342	≈ 1 year
Total	**24**	**691**	**≈ 2 years**

Figure 5.
Pattern of sessions in the "listen and play" experiment.

immediately before (see Figure 6). This will be undertaken using the "zygonic" music-analytical techniques developed by Ockelford (1999, 2002, 2004, 2005a, 2005b, 2006a). The analysis that is undertaken will subsequently be used to construct hypotheses as to the nature of the mental processing underlying Paravicini's output (*cf.* Ockelford, 2006b).

ZYGONIC THEORY

Zygonic theory holds that musical coherence is based on a sense of derivation, whereby a given aspect of musical sound (a particular pitch, harmony, tonality, interonset interval, duration or meter, for example) is felt to *imitate* another, something which typically occurs non-consciously. The cognition of derivation between musical elements is predicated on the presence of "interperspective

Chromatic Blues – Derek's Rendition 1
(immediately after hearing the piece for the first time)

Figure 6.
Paravicini's first attempt at playing Chromatic Blues — his "Rendition 1".

relationships"[14] — cognitive constructs through which, it is hypothesized, percepts may be compared (*cf.* Krumhansl, 1990, p. 3). Interperspective relationships may be regarded as forms of "link schemata" (Lakoff, 1987, p. 283), which inhabit the mental space pertaining to music processing (Fauconnier, 1985/94). Such relationships potentially exist between any features of musical events. In most circumstances they are formulated unthinkingly, passing listeners by as a series of qualitative experiences. However, through metacognition, interperspective relationships may be captured conceptually and assigned values, commonly expressible as a difference or ratio.

Figure 7 shows interperspective relationships symbolized by an arrow with the

(14) "Interperspective": a term coined by Ockelford (1991) to mean "between *perspects*" (that is, "*per*ceived a*spects*") of music; used in contradistinction to the term "parameter", which is reserved solely to refer to the physical attributes of sound. Hence the perspect "pitch", for example, most closely corresponds to the parameter "frequency", though the connection between the two is far from straightforward (*cf.* Meyer, 1967, p. 246).

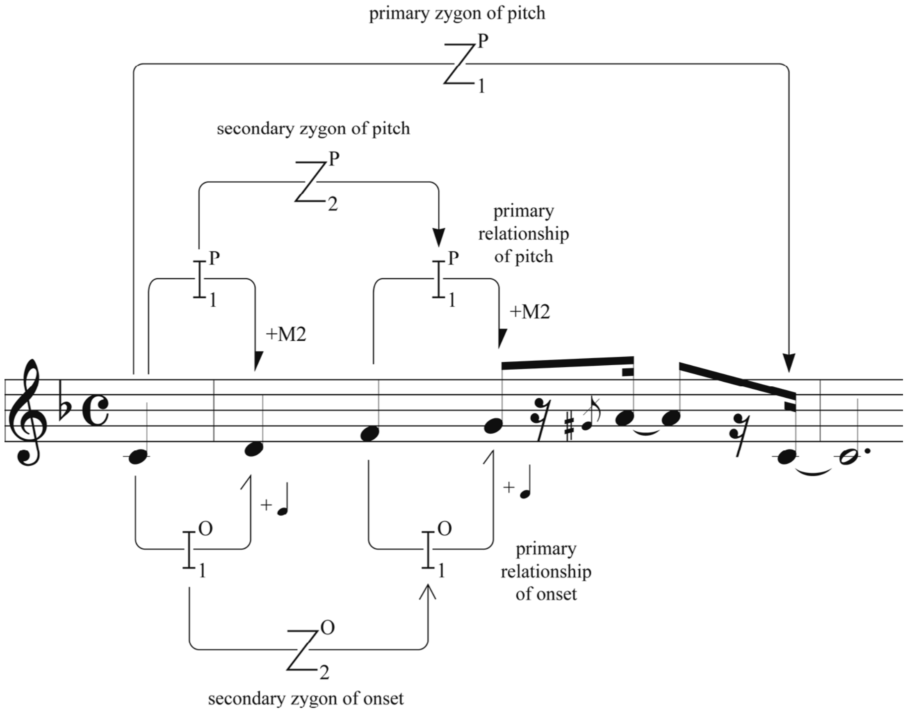

Figure 7.
Examples of interperspective and zygonic relationships.

letter "I" superimposed. Superscripts indicate the features concerned, each represented by its initial letter — here "P" for "pitch" and "O" for "onset". Relationships can be of different *levels*, with "primary" relationships potentially linking percepts directly, "secondary" relationships connecting primaries, and "tertiary" relationships comparing secondaries (Ockelford, 2002). The level of a relationship is indicated by the appropriate subscript (here, 1). The values of the pitch relationships (shown near the arrowheads as "+M2") have two components, "polarity" (which here is postiive, showing that the intervals are ascending) and "magnitude" (a major second). Similarly, the values of the relationships of onset indicate both temporal polarity and magnitude (a crotchet).[15]

Interperspective relationships through which imitation is cognized are deemed to be of a special type, termed "zygonic" (Ockelford, 1991, pp. 140ff).[16] Zygonic

(15) Observe that arrowheads may be open or filled — the former showing a link between *single* values, and the latter indicating a *compound* connection within or between "constants" (typically, values extended in time) — implying a network of relationships the same. For a fuller explanation, see Ockelford (1999).

(16) From the Greek term "zygon" for "yoke", implying a union of two similar things.

relationships, or "zygons", are depicted using the letter "Z". In Figure 7, the primary zygonic relationship of pitch reflects the apparent derivation of last note of the opening phrase from the first. The secondary zygons of pitch and onset (indicated through the subscripts "2") show imitation at a more abstract (intervallic) level. Observe the use of *full* arrowheads, which signify relationships between values that are the same. *Half* arrowheads are indicative of difference, and are used in a zygonic context to show approximate imitation.[17]

THE *CHROMATIC BLUES* — A MUSICOLOGICAL ANALYSIS OF PARAVICINI'S "RENDITION 1"

In the first session, certain aspects of Paravicini's first rendition of bars 1 and 2 can be considered to be derived in a straightforward way from the opening of *Chromatic Blues*, with events being imitated in sequence. Rhythmically, for example, the origin of 80% of Paravicini's material is attributable in this way, as opposed to 39% in the domain of pitch — an average of 59%.[18] Hence a good deal of what he produces

(17) Given the interdisciplinary nature of this article, it is particularly important to be clear about the status of zygonic relationships. They are *hypothetical constructs* intended to represent aspects of the typically subconscious cognitive processing that can be assumed to occur when we attend to, create or imagine music — a supposition suggested by the structural regularities of pieces, which, as Bernstein asserts, offer "a striking model of the human brain in action and as such, a model of how we think" (1976, p. 169). Of course, the notion of a zygonic relationship can at best offer only a much-simplified version of certain cognitive events that may be stimulated by participation in musical activity. However, while simplification is necessary to make headway in theoretical terms, it is important to bear in mind that the single concept of a zygon bequeaths a substantial perceptual legacy, with many possible manifestations, not only potentially linking individual pitches, timbres, dynamics, durations and interonset intervals, but also prospectively existing between tonal regions, textures, processes and forms the same; over different periods of perceived time; functioning reactively or proactively; and within the same and between different pieces, performances and hearings. Given this variety, there is, of course, no suggestion that the one concept represents only a single aspect of cognitive processing. Hence, empirical evidence in support of the theory is likely to be drawn from a diversity of sources. Currently, for example, one can point to experiments in auditory processing (such as the "continuity illusion", summarised in Bregman, 1990, pp. 344ff) and work on expectation in a musical context, particularly that involving the perceptual restoration of omitted or obscured notes (for instance, DeWitt and Samuel, 1990), to support the presence of proactive zygonic-type processes (Ockelford, 1999, p. 123). There is general support for the theory too in the wide range of music-theoretical and analytical sources in which the fundamental importance of repetition in music is acknowledged. These are itemised in Ockelford (1999). Similar acknowledgements are made by Borthwick (1995), as a background to the exposition of his metatheoretical framework to which the notions of identity (and non-identity) are central. Perhaps most pertinent of these to zygonic theory is the assertion of Cone (1987, p. 237), made in relation to the derivation of musical material, that "y is derived from x (y ← x), or, to use the active voice, x generates y (x → y), if y resembles x and y follows x. By 'resembles', I mean 'sounds like'…".

(18) These measures of "zygonicity" are explained in Ockelford (forthcoming).

remains unaccounted for in direct derivational terms — a tendency which characterises his Rendition 1 as a whole. The remaining material could either have been created afresh, or have stemmed from one or any combination of three sources: elsewhere in *Chromatic Blues*, other pieces (more or less specifically) or other pieces (more generally, as features of style). Moreover, since material can be derived from a multiplicity of models (Ockelford, 2005a, p. 114), those features of Rendition 1 that had direct sequential equivalents in *Chromatic Blues* may additionally have originated elsewhere.

These potential sources will now be considered in turn in relation to the opening bars. The zygo-analytical approach that is adopted will seek to identify relationships through which fragments of musical material can reasonably be considered to be derived from one another, according to the similarity and relative salience of the events concerned. An important factor in the current context is the researchers' detailed knowledge of Paravicini's repertoire, which informed the following account of the possible connections between pieces. Clearly, this method, which relies so heavily on the intuitive judgements of people who know Paravicini well, potentially lacks of objectivity. However, it is important to emphasise the ontological status of the analyses that follow: they are only intended to be indicative of the *type* of musical connections that appear to be present (and therefore, as a further step to be taken in due course, of the *type* of cognitive processes that created them). This is as much as can be attained through current music-analytical techniques, which are, by nature, subjective. But, to reiterate, it is the *principles* they illustrate that are more important than the verifiability of any particular aspect of them.[19]

With regard to material derived from elsewhere in *Chromatic Blues*, it appears that the first four bars were a particularly rich vein for Paravicini to tap. Zygonic analysis suggests that the transformational techniques adopted included the reordering of material in the domain of pitch, whereby, for example, the contour of the *second* phrase (which begins in the same way as the first) was used at the *beginning* of his version. This emphasises the D major harmony that was particularly salient in the original (as it provided an unusual tonal goal for the second phrase of the melody). In addition, the ascent in the bass line from F to F♯ in bar 1 seems to echo the transition from C to D♭ in the original, effectively transforming a highly unusual move this early in proceedings into one that is stylistically commonplace. Further reordering occurs as the descent to middle C that ends the first phrase is moved in Paravicini's rendition to the end of the second. In the domain of rhythm, the opening phrase (without the acciaccatura) is used twice, conferring a straightforward symmetry on proceedings that is not found in the original. Hence,

(19) Methodologically comparable with the approach adopted, for example, by John Livingston Lowes (1951) in his detailed investigation into the sources of Samuel Taylor Coleridge's imagery; as Margaret Boden points out (2004, p. 127), "'evidence' and 'probably' are the best we can expect in investigations of this kind."

it appears that in the process of creating his version, Paravicini separated elements of pitch and rhythm and re-synthesised them to produce material that was closely related to the original, though distinct from it.

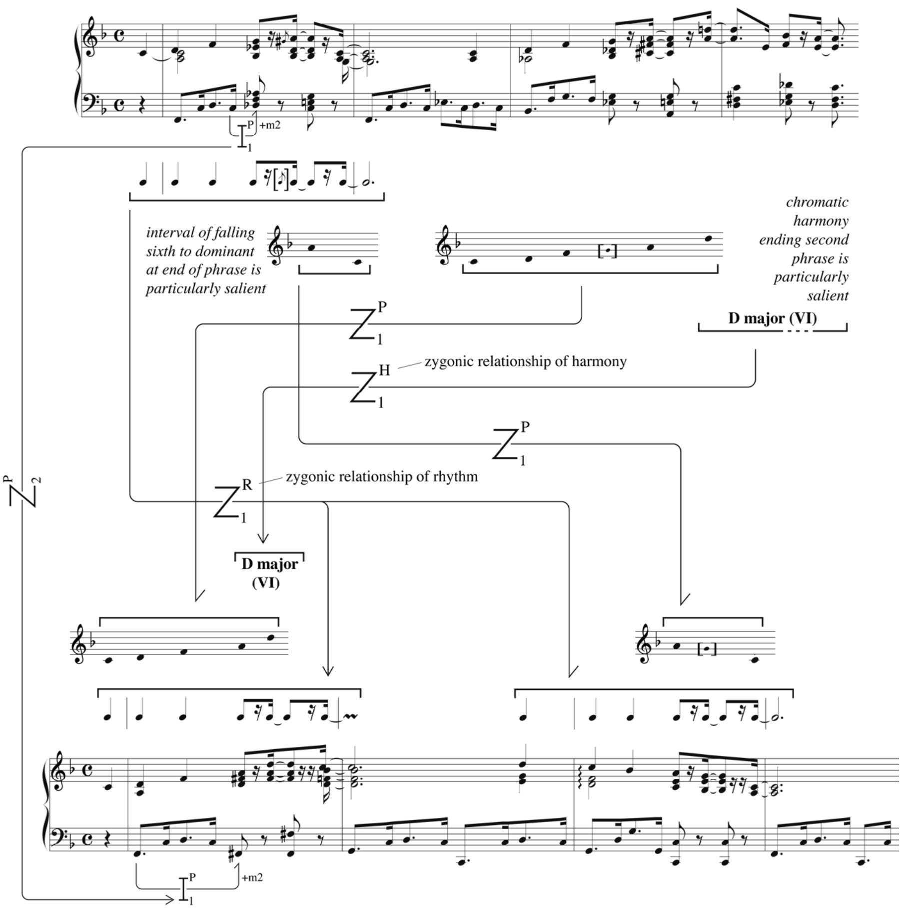

Figure 8.
Hypothesised derivation of the opening of Paravicini's Rendition 1 from Chromatic Blues.

In parallel with these intraopus connections, it appears that Paravicini borrowed material from other pieces, both generally (through stylistic features) and specifically (from individual works; a technique that is characteristic of traditional jazz — see Berliner, 1994, pp. 103ff). Figure 9 shows some of the potential relationships with other pieces that the researchers believe may have played a part in the formulation of the opening bars of Paravicini's first attempt at playing *Chromatic Blues*.

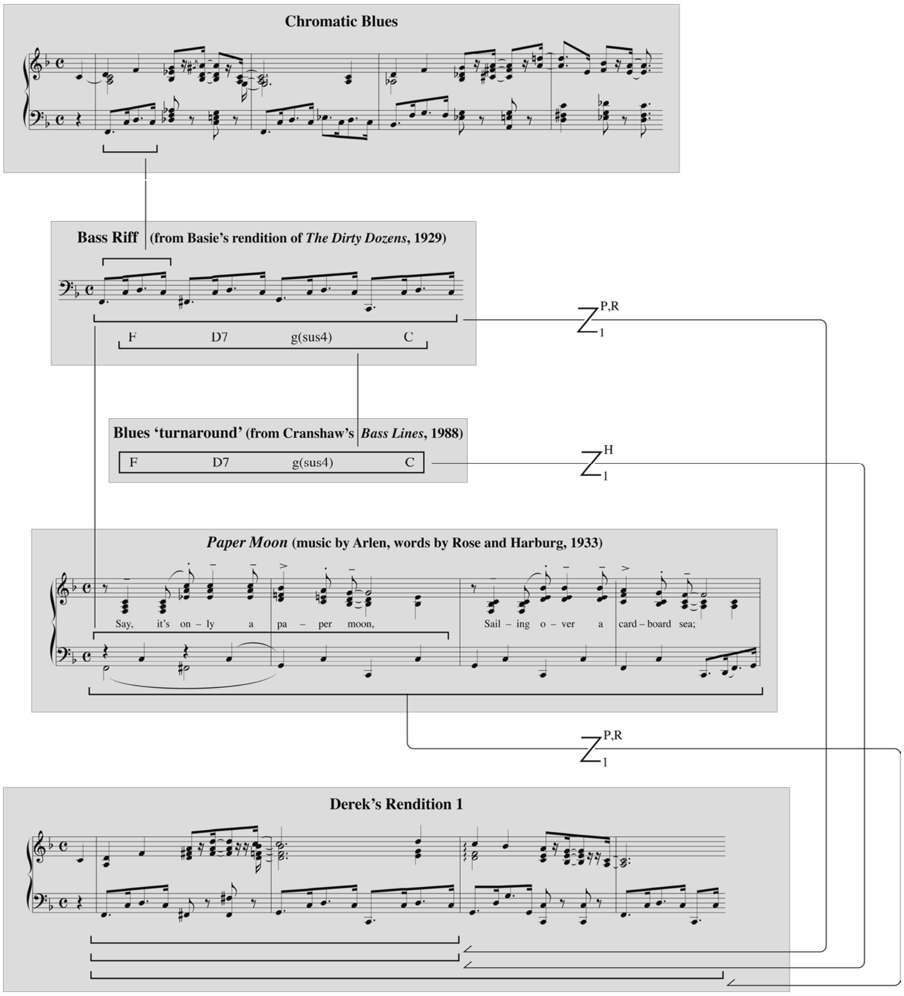

Figure 9.

Hypothesised derivation from other pieces of material from the opening of Paravicini's Rendition 1.

For example, it is hypothesised that the first two bars of the bass line in Paravicini's Rendition 1 derive from a standard bass riff (exemplified here in an excerpt from Count Basie's rendition of *The Dirty Dozens*, 1929), whose harmonic pattern also constitutes a widely-used Blues "turnaround". Moreover, the bass line and harmonies of the first four bars of Rendition 1 closely resemble those used in the chorus of *Paper Moon*. It is impossible to say the extent to which these pieces (with which Paravicini was known to be very familiar) and others that could be identified *actually* played a part in the creation of Rendition 1 — though the probability of complex, integrated patterns of pitch and rhythm such as those identified resembling others by chance is statistically remote. In summary, then, Figure 9 is intended to offer an indicative and partial account, rather than one that is prescriptive or exhaustive.

How were these differing materials, culled from a diversity of sources, brought together within a new and coherent musical whole? According to zygonic theory, a necessary (though not a sufficient) feature of all musical coherence is the ubiquitous presence of structural (that is, zygonic) relationships (Ockelford, 2005b, pp. 84ff). In relation to the first four bars of Rendition 1, the position may be summarised as follows (see Figure 8). The pitch contour of the melody is based on the movement from middle C to the C an octave above, followed by a return to middle C through approximate retrogression of the opening motive. These two gestures are also connected through repetition, whereby the last two notes of the initial figure are used to kick off the second. This reiteration is mirrored in the bass line with the movement from G to C and the harmonic shift from ii to V, together giving the effect of picking up from where the first gesture left off and then taking it in a new direction. Rhythmically, the two halves are identical.

It is possible to synthesise musical fragments from a variety of sources because of the "chameleon" effect (Ockelford, 2005b, pp. 99ff), whereby certain features of chunks of music can be modified without their identities being compromised, enabling them to coexist within a common framework of tempo, tonality, timbre and loudness. Specifically, in the case of Rendition 1, Paravicini adopts a tempo of 107 crotchet beats per minute (slightly faster than the ♩ = 100 of *Chromatic Blues*) while using the same metrical framework (common time). Both *Chromatic Blues* and Rendition 1 utilise sets of context-specific transition probabilities in the domain of pitch that give the sense of the tonality of F major, and, broadly speaking, the feel of the "Blues".

The "chameleon" effect is one way in which the creation of the opening bars of Rendition 1 represents a balance of forces between the deployment of extant materials and the need for what is produced to make musical sense on a moment-to-moment basis. Inevitably, it is the latter that dominates, as (for example) the construction of the second melodic gesture illustrates. Having ascended an octave and arrived at the harmony gmin^{7}sus^{4} (from F via D^{7}), the stylistically-attuned ear would typically expect a melodic descent and a return to the tonic (F). To achieve this, Paravicini has to create a new link (the D-C taken from the end of the first phrase, setting in place a scalar motion which continues to the A) before being able to deploy a modified version of the ending of the first motive from *Chromatic Blues*.

The dominance of the internal forces of coherence becomes more and more evident as Rendition 1 progresses. For example, in *Chromatic Blues*, following the opening four bars, there is a highly chromatic passage (labelled "$B_{1.1}$" in the structural analysis shown in Figure 3). This is linked to opening ("$A_{1.1}$") via the pivot note D, with serves successively as the root of the D major harmony with which the

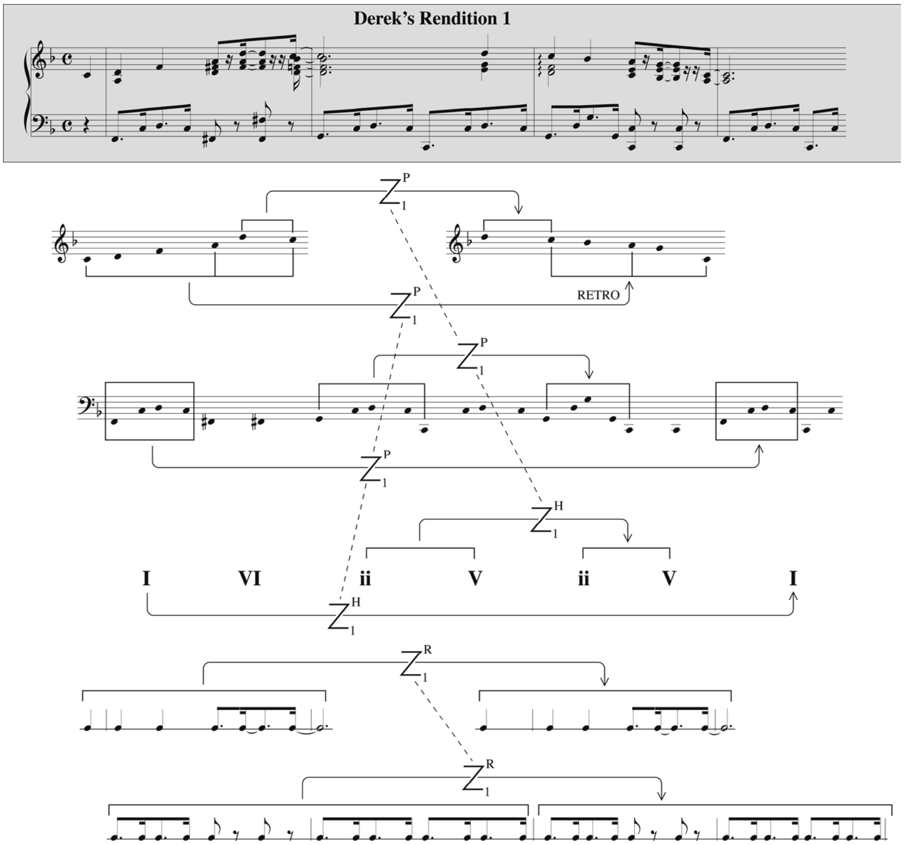

Figure 10.
The key structural features of Paravicini's Rendition 1 (bars 1-4).

opening section ends (in bar 4) and the third of the B♭ major chord with which the chromatic sequence begins. However, in Paravicini's Rendition 1, this link is not available since his first section ends on middle C. Hence, he was more or less compelled to take another tack (irrespective of whether her could remember what actually occurred at this point). What possibilities were open to him? Working within the constraint that he had to be as faithful as possible to the original, Paravicini did the musically obvious (perhaps the only) thing and returned to the opening for the source of his next swatch of material. However, given that he was aiming to emulate *Chromatic Blues* as far as he could, this left Paravicini with the structural difficulty of the need for contrast (including key change) at this juncture. His solution was to reharmonise the end of the first phrase in A minor, incorporating the stylistically unusual transition from D major (bars 5 and 6). The A minor tonality continues into the second phrase, at first through straightforward reharmonisation (bars 6 and 7) but subsequently through transposition and modification of the melodic descent first heard in bar 3, yielding a more authoritative A minor cadence (bars 7 and 8).

At this point, Paravicini's solution to the problem of tonal contrast presented him with a further challenge. Structurally (following the *Chromatic Blues* model), a return to the opening is demanded, both tonally and thematically. Hence, within a very short space of time (beats 2 and 3 of bar 8) he needed the music to modulate from A minor to prepare for a return to F (through its dominant, C). This he achieved with a V-I sequence that continues into the reprise of the opening, logically binding the two sections together (through the series of harmonies D-G-C-F). Paravicini then repeated bars 1 to 4 (with only minor changes in detail), again utilising the structure of *Chromatic Blues* divorced from its content. It is fascinating to think that Paravicini was presumably aware (at some level) that by repeating what he had first played in Rendition 1 he was inevitably producing something that — once more — was different from the original. But we can also assume that he intuitively knew that musically it made more sense to repeat an "error" rather than to try for a more accurate recall of the opening theme at the second attempt.

At this juncture, then, Paravicini had produced a piece in the form $A_{1.1}$ $A_{1.2}$ $A_{2.1}$. If he were to continue to follow the *Chromatic Blues* structural model — $A_{1.1}$ $B_{1.1}$ $A_{1.2}$ $B_{2.2}$ C — albeit approximately, then a further version of A would be required, modified so as to produce an unambiguous sense of completion, with a strong perfect cadence in F major… and this is precisely what we get. The opening melody appears for a fourth time, but the feeling of forward motion engendered by the rocking motive in the bass is curtailed, replaced with spread chords. The impending sense of closure is reinforced by a move to the subdominant (B♭), which replaces the G minor harmony. Finally, within this four-bar section (functioning as "$A_{1.3}$" in structural terms) Paravicini's rendition nods in the direction of the coda of *Chromatic Blues*, through an additional perfect cadence in the final bar in which right-hand quaver triplets (incorporating blues notes) extend upwards to fifth octave F, while the bass reaches down two octaves. These similarities with the *Chromatic Blues* coda are sufficient to capture something of its spirit, capping the piece off through the injection of a new rhythm and texture. Once more, the legacy of the preceding phrase meant that some development of the original material was inevitable.

In summary, it is evident that the requirement for musical coherence in Paravicini's Rendition 1 produces a range of solutions, some of which appear to have been hastily constructed in response to moment-to-moment needs (such as the move to A minor in bar 6, and the return to F major in bars 8 and 9), while others suggest a greater degree of structural anticipation, such as the reduction in the level of activity in the final phrase initiated at its outset through the chords in bar 13. With regard to the derivation of material from *Chromatic Blues*, there is, as we have seen, significant use of both its content and structure in section $A_{1.1}$ of Rendition 1. In the following sections $A_{2.1}$ $A_{1.2}$ and $A_{1.3}$, however, only structural relationships are appropriated — although, inevitably, given the repetition in *Chromatic Blues*, this results in some of the original content being replicated too (as in section $A_{2.1}$). It is only in the final bar (the coda) that an unambiguous sense of derivation of content returns.

From musicological analysis to psychological hypothesis

What does this musicological analysis suggest to us about Paravicini's mental processing? What is it reasonable to infer? Clearly, it is important to reinforce the methodological limitations inherent in this approach, mentioned above. For example, while we can assume that the music Paravicini produced bore some relationship to his mental representations of *Chromatic Blues*, it would not be safe to presume that the mappings between model and product were exclusive or regular. That is, it seems highly likely — indeed, almost certain — that there were elements of the traces in his memory that were never realised in sound. Partly this situation will have arisen due to Paravicini's (unwitting) intuitive drive to produce something that was musically coherent based on imperfect recall. This may have resulted in his accessing long-term memories that would otherwise have lain dormant, for example, and (as the analysis above shows) creating new material that would not otherwise have been formulated. Beyond this, however, it may also have been the case that the motor processes required for the reproduction influenced what he played (through the use of purely kinaesthetic schemata that may have been triggered) and, indeed, that these same overlearnt motor patterns may have been the source of musical material that bore no direct auditory relationship to that contained in *Chromatic Blues*. Nonetheless, it is my belief that the music that Paravicini produced provides sufficient evidence for a number of reasonable assumptions to be made about the cognitive processing that lay behind his efforts.

We start by reaffirming the assumption, based on past experience of working with Paravicini, that, since he was requested to do so, he would have tried to make his version of *Chromatic Blues* as faithful as to the original as he could. It is a reasonable assumption, because he did not reproduce the piece accurately, that it lay beyond the capacity of his working memory. So what *did* he remember? And — just as importantly — what was he *not* able to recall? It is immediately apparent that what Paravicini did not do was to recreate *Chromatic Blues* sequentially up to a certain point and then stop (as would a computer with a buffer of limited capacity). As we observed above, in producing his Rendition 1, at once an act of creation and reconstruction, he utilised specific items from the beginning and end of *Chromatic Blues*, higher level structural features from the piece as a whole, and features (such as tempo and metre) that were present throughout. That is to say, he appears to have built up and stored in short-term memory a *bundle* of musical fragments and attributes from various locations in the original piece, of varying lengths, types and degrees of abstraction. With regard to the opening bars, for example (see Figure 6), a *fragment* that was preserved in terms of both pitch and rhythm was the opening motive in the bass-line. Subsequently (from the second half of the first bar) it was only the rhythm that was recalled accurately. An *attribute* that was stored was the tonality. Since these cognitive "objects" and their forms of transformation are *music-specific*, it is evident that Paravicini's Rendition 1 offers support to Berz's notion of dedicated music circuitry in working memory.[20]

What was Paravicini's "short-term memory bundle" like? The fact that *Chromatic Blues* apparently exceeded the capacity of his short-term memory meant that there would inevitably have been competition among its elements, whereby some would be captured and retained while others would not. Why did certain items find their way into the bundle while others (apparently) did not? Why were some more durable than others? We may surmise that among the determining factors in this process were *salience*, including the immanent qualities of a particular item and how these related to the perceived attributes of surrounding stimuli in terms of similarities and differences (*cf.* Ockelford, 2005b, pp. 81ff); *structure*, including the degree of internal regularity of an item which may permit its parsimonious encoding (Ockelford, 1999, pp. 115ff); *resilience*, the degree to which an item could retain its encoded identity among a welter of interference from rivals; and *reinforcement*, brought about through the repetition of items (see Ockelford, 2004). It seems that these factors frequently took effect in combination. Consider, for example, the opening rhythmic motive in the right-hand part of *Chromatic Blues*, which Paravicini reproduced accurately (though without the grace note) — indeed, it forms the basis of much of his Rendition 1, being used eight times. We can assume this motive had particular salience, being among the first things that Paravicini heard, with no pre-stimulus interference; it had moderate rhythmic regularity (for example, zyg_1 [interonset interval] = 0.6)[21] that proved to be resilient in the face of competing post-stimulus input; and it was heard twice in the course of *Chromatic Blues*, offering reinforcement. Hence it appears that the "short term memory bundle" should not be conceived of as a collection of auditory traces (and their abstractions) laid down like rock strata, with no interaction, each layer consolidated at a certain point in time. Rather, it seems likely that the system dynamically evolved as *Chromatic Blues* unfolded, and continued to develop during his Rendition 1. Just how the serial order of features and fragments would be reconstructed is considered below, through the notion of "tagging" (*cf.* Kieras, Meyer, Mueller and Seymour, 1999).

Next, we consider the manner in which memories of items from other pieces were stimulated — that is, how did short-term memory engage with long-term? The

(20) Clearly, this could be explored with further empirical work; in the meantime it is of interest to note that Paravicini is happy to engage in conversation while playing, without apparently diminishing the quality of his musical output.

(21) That is to say, of all the potential relationships of interonset interval between the six notes in the series, 60% were potentially zygonic. See Ockelford (2005a, p. 94).

indicative analysis in Figure 9 suggests that long-term memory traces were activated through the perception of new items with which they shared varying degrees of similarity, wholly or partly comprising the same perceptual features or bearing the same relationships *between* perceptual features (of varying degrees of abstraction; see Ockelford, 2002). The long-term traces may have pertained to one piece or more, and may have been either "veridical" or "schematic" in nature (that is, relating either to particular episodes or to probability matrices — "style systems" — deriving from many such episodes; see Bharucha, 1987, and Ockelford, 2006a, pp. 126ff). Evidently, one memory trace was able to stimulate another (in the case of the Bass Riff and *Paper Moon*, for example), resulting in only an indirect relationship between features of *Chromatic Blues* and Rendition 1. For Paravicini, the process of stimulation was rapid and unthinking. The manner in which the memory traces in short-term memory subsequently found a place in long-term storage cannot be discussed in detail here, though analysis of Paravicini's subsequent renditions of *Chromatic Blues* provide a number of important insights in this regard to be published in due course (Ockelford, forthcoming).

Finally, how did the process of "creative reconstruction" work? This can be understood using Baddeley's analogy of a "central executive" — but here a "*musical* executive" — whose primary input was the auditory information deriving from the recording of *Chromatic Blues* and whose secondary input comprised Paravicini's memories of other pieces, fragments, attributes and style-systems. The executive evidently had two immediate outputs: the mental image of the auditory trace of Rendition 1 and the necessary motor instructions to realise this on the keyboard. (Just how the motor output functioned, and how this and the auditory output interrelated are major topics in themselves, and beyond the scope of the present paper.) From Rendition 1, we can surmise that the guiding principles under which the Paravicini's musical executive operated were to produce something that made "musical sense" and that resembled, as far as possible, *Chromatic Blues*. In the case of potential conflict, the former would take precedence over the latter.

These general principles can be unpacked to facilitate a more detailed understanding of the processes that we may surmise occurred. Zygonic theory holds that a *necessary* condition for music to make sense is that every feature of each perceived sonic event should be related to another or others, such that each is felt to derive from or generate at least one other through imitation. Even this seemingly stringent condition is not *sufficient* to guarantee immediate musical comprehensibility, however. For that, the relationships between simultaneous and successive events in the domains of pitch and perceived time and, in some instances, the relationships between *these* have also to be derived from other pieces and anticipated according to the probability of their past occurrence (Huron, 2006). This suggests that a supersaturation with repetition is both typical and necessary for pieces to be readily comprehensible (Ockelford, 2006a), implying that a similarly high level of "background" structure was a prerequisite for coherence in whatever music Paravicini improvised.

Taking all these observations into account, it appears that the musical executive must relate:

1. to perceptual input (through the central executive);
2. to the short-term memory bundle that holds musical fragments and attributes of varying types in readiness for use;
3. to long-term memory, enabling mutual engagement with short-term memory traces; and
4. to the "outputs" necessary to recreate the inner auditory images in sound.

It appears that as music is *heard*, the musical executive must have the capacity

1. to process incoming perceptual input, constantly searching for the repetition (at primary, secondary or tertiary levels of abstraction from the perceptual surface) that underpins musical structure and permits parsimonious encoding and "chunking";
2. to prioritise what is sent to the short-term memory bundle, according to salience, reinforcement and other factors;
3. to "tag" elements in a manner that shows how they were related (to facilitate future retrieval);
4. to send encoded fragments and features to long-term memory to locate potential "matches"; and
5. to receive the potential matches from long-term memory and to process these in parallel with incoming perceptual input to inform the listening process.

And it appears that as music is *recreated* immediately after hearing the musical executive must have the capacity:

1. to draw on short-term memory traces, using their "tags" to recreate the relationships between them wherever possible;
2. to call-up an (indicative) multidimensional style system from long-term memory that is congruent with the elements in the short-term memory bundle, to provide a framework into which they can be slotted;
3. to select items or features from long-term memory that fit within the evolving style system (albeit with modification) and that would potentially fill the lacunae occasioned by limitations of short-term memory;
4. to transform these as necessary, through the addition, deletion or modification of material;
5. to synthesise the selected elements, integrating them "vertically" (harmonically) and "horizontally" (melodically) within the unfolding matrix of pitch and perceived time;
6. to create new material within the style system, as required, in order to provide links between given material, fill potential gaps and ensure short-term coherence; and
7. to track and direct the musical narrative simultaneously at different architectonic and hierarchical levels to ensure longer-term coherence.

Remarkably, this synthesis of schematic and veridical forces must all occur in "real time" as an improvisation proceeds and which in Paravicini's case appears to

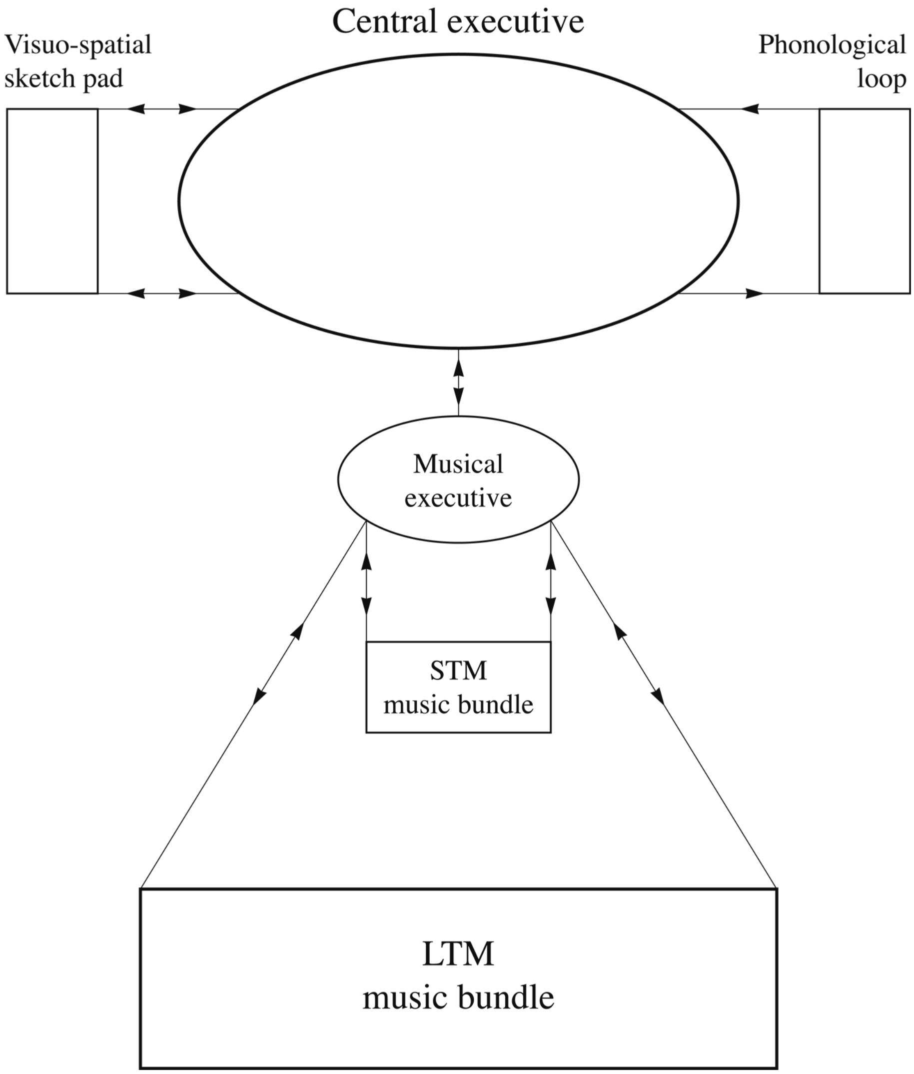

Figure 11.
The possible disposition of a "music module" in working memory.

have taken place quite unwittingly, with no conscious intervention; certainly he was unable afterwards to reflect upon what he had done.

CONCLUSION — A NEW MODEL OF MUSIC IN WORKING MEMORY

To conclude, a visual representation of what is evidently a *composite* hypothetical "music module" and how this may fit in with other aspects of working memory is provided in Figure 11. The main development of the Baddeley/Berz model is the notion of a *musical* executive, which relates closely to the "central executive" and, indeed, may even be a subset of it. It seems likely that the musical executive, with its wide range of functions outlined above may comprise several subcomponents. By extension, it may be that similar domain-specific executives exist in other areas.

Clearly, opinions may differ as to the extent to which this model does or does not give an adequate account of Paravicini's musical processing within his working memory. More contentious, though, is the extent to which it may be reasonable to generalise from this single and exceptional case study to hypothesise how musical memory functions more widely. This is a challenge for future research, with Paravicini, other savants, and a range of subjects with varying levels of musical experience and expertise. However, it is worth noting that, at the very least, there is nothing in the model presented here that contradicts the Baddeley/Berz conjecture and the growing body of evidence that supports it.

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• ¿ Un módulo musical en una memoria de trabajo ? Evidencia de la interpretación de un experto musical

Este artículo investiga la posible existencia y naturaleza de un “módulo musical” en la memoria en proceso partiendo de Baddeley (1986) y Berz (1995). La evidencia es extraída de la interpretación de un músico experto al escuchar e interpretar una pieza desconocida. Su habilidad para interiorizar imágenes sonoras de considerable complejidad sobre el teclado con inmediatez e inusual facilidad técnica ofrece una oportunidad extraordinaria para extraer alguna hipótesis del trabajo de una mente musical de una forma validada directa y ecológicamente a través, únicamente, de respuestas musicales. Éstos son temas para un análisis musicológico inicial empleando la teoría “zygónica” (Ockelford, 2005a, 2005b), que busca explicar cómo la estructura y el contenido de las respuestas musicales de un experto se derivan de los estímulos y de otras fuentes, y cómo ambos se integran dentro de un todo musical coherente. La asunción metodológica subyacente es que las relaciones sonoras percibidas identificadas ofrecen evidencias de procesos que se convierten en hipótesis que subyacen en el aprendizaje, el almacenamiento y la recuperación de elementos musicales en el proceso cognitivo.

• Un modulo musicale nella memoria di lavoro ? Una prova tratta dall’esecuzione di un prodigioso genio musicale

Il presente articolo indaga la possibile esistenza e la natura di un “modulo musicale” nella memoria di lavoro, prendendo le mosse da Baddeley (1986) e Berz (1995). Una prova è dedotta dall’esecuzione di un prodigioso genio musicale, il quale ha ascoltato e poi riprodotto un brano a lui sconosciuto. La sua abilità di realizzare alla tastiera immagini uditive interiorizzate di considerevole complessità, con immediatezza e con un’abilità tecnica inusuale, offre una rara opportunità di dedurre qualcosa dei meccanismi della mente musicale in modo diretto ed ecologicamente valido – ossia attraverso risposte puramente *musicali*. Queste ultime sono sottoposte ad una iniziale analisi musicologica con l’ausilio della teoria “zigonica” (Ockelford, 2005a, 2005b), la quale cerca di spiegare il modo in cui la struttura ed il contenuto della produzione del genio derivino dallo stimolo e da altre fonti, e come entrambi siano intrecciati in un tutto musicale coerente. L’assunto metodologico soggiacente è che le relazioni sonore percepite così identificate offrano una forte prova a favore di processi che si ipotizza siano alla base dell’apprendimento, della memorizzazione e del recupero di elementi musicali nella cognizione.

• Un module de musique dans la mémoire de travail ? Des données tirées de l’interprétation d’un prodige musical

Après Baddeley (1986) et Berz (1995), nous étudions, dans cet article, la possibilité de l’existence et la nature d’un « module de musique » dans la mémoire de travail.

Les données proviennent de l'interprétation d'un musicien prodige qui est capable de jouer une pièce inconnue de lui après l'avoir entendue. Sa capacité de créer des images auditives intériorisées d'une grande complexité et de les réaliser au clavier de façon immédiate et avec une grande facilité technique, nous donne une occasion rare de chercher à comprendre comment fonctionne la pensée musicale. Nous avons fait cela de manière directe et écologiquement valable en tenant uniquement compte de ses réactions *musicales.* Celles-ci sont soumises à une première analyse sur la base de la théorie « zygonique » (Ockelford, 2005a, 2005b) ; on cherche ainsi à expliquer la façon dont la structure et le contenu du rendu du prodige proviennent du stimulus et d'autres sources et comment les deux sont unis pour créer un ensemble musical cohérent. L'hypothèse méthodologique est que les rapports sonores perçus et identifiés sont une preuve sérieuse de l'existence de processus que l'on pense être à la base de l'apprentissage, du stockage et de l'extraction des éléments musicaux dans la cognition.

• Ein Musikmodul im Arbeitsgedächtnis ?
Belege aus der Performanz eines hochbegabten musikalischen Savants

Dieser Artikel untersucht die mögliche Existenz und Wirkungsweise eines „Musikmoduls" im Arbeitsgedächtnis nach Baddeley (1986) und Berz (1995). Belege dafür werden aus der Performanz eines hochbegabten musikalischen Savants beim Hören und Nachspielen von unbekannten Stücken zusammengetragen. Seine Fähigkeit, internalisierte Klangvorstellungen von beträchtlicher Komplexität auf dem Klavier sofort und mit ungewöhnlicher technischer Fertigkeit zu realisieren, bietet eine seltene Gelegenheit, einzelne Funktionsweisen des Musikverstandes auf direkte und ökologisch valide Weise zu untersuchen – durch rein musikalische Reaktionen. Diese werden einer ersten musikwissenschaftlichen Analyse entsprechend der „zygonischen" Theorie unterzogen (Ockelford, 2005a, 2005b). Dadurch soll erklärt werden, wie Struktur und Inhalt im Spiel des Savants vom Stimulus oder anderen Quellen abgeleitet und wie beide in ein kohärentes musikalisches Gesamtgefüge verwoben werden. Die zugrunde liegende methodologische Annahme ist, dass die so identifizierten, wahrgenommenen Klangbeziehungen starke Belege für Prozesse bieten, die möglicherweise die kognitive Basis für das Lernen, Speichern und den Abruf musikalischer Elemente sein könnten.