What if Musical Skill, Talent, and Creativity were just a Matter of Memory Organization and Strategies?

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Abstract

This article discusses musicians' skill, talent and creative aptitudes, focusing on musical reading and musical performance. Inter-individual differences between expert and non-experts are discussed in terms of specific encoding and retrieval strategies that are described in expert memory models.

Keywords: musical reading; expertise; competence; talent; creativity; eye tracking.

The old debate between nature and nurture in music expertise (Howe & Sloboda, 1991; Gagné, 1999) has been recently reactivated (Hambrick & Tucker-Drob, 2015). What accounts for the variability of musicians' skill, talent and creative aptitudes? According to Ericsson, Krampe & Tesch-Romer (1993) and their notion of deliberate practice, expertise may be acquired through repetition, practicing many hours per day, rather than by a supposed innate ability. After having asked expert violinists and pianists about the amount of time they practice every day, these authors observed that musicians had accumulated at 20 years old, 10,000 hours on average. This amount of time was thousands of hours more than the average for less skilled musicians. They argue: "*many characteristics once believed to reflect innate talent are actually the result of intense practice extended for a minimum of 10 years.*"

In contrast, for Hambrick & Tucker-Drob (2015), musical skill is for a large part genetically determined: nature and nurture interact with each other. Using the National Merit Twin Sample, they ran correlation analyses concerning genetic and environmental effects according the level of music practice and accomplishment, investigating whether musical accomplishment is determined by genetic factors or/and extensive practice. They used gene-environment-correlation (rGE) to enhance genetic influences on individual variations in individuals' exposure to a specific environment (for review Rutter, Moffitt & Caspi, 2006). They assert: "*Focusing on musical accomplishment in a sample of over 800 pairs of twins, we found evidence for gene-environment correlation, in the form of a genetic effect on music practice. However, only about one quarter of the genetic effect on music accomplishment was explained by this genetic effect on music practice, suggesting that genetically influenced factors other than practice contribute to individual differences in music accomplishment.*" They found that accomplished musicians are those who practice much more than others, but also that genes have a larger influence on musicians who practice.

Meinz & Hambrick (2010) claim that deliberate practice is necessary but not sufficient to explain individual differences in musical expertise. They proposed to musicians to perform a sight reading task in which pianists played pieces of music without preparation. Regardless of the deliberate practice, they observed that pianists with a high level of working memory capacity performed better than others.

Would it be possible that skill, talent and creativity were just a matter of memory organization and strategies? More precisely, are skill, talent and creativity the result of specific encoding and retrieval strategies that are described in expert memory models? That is the point of this paper, focusing on musical performance rather than the musical composition, although this distinction is blurred in improvisation.

It has been shown that models of expert memory may shed light on musical reading and performance (Drai-Zerbib & Baccino, 2005). But what about virtuosity? Motor virtuosity represents fast, dexterous, accomplished, precise motor actions of highly skilled musicians (Altenmüller, Wiesendanger & Kesselring, 2006) as a result of intensive practice (Furuya, & Altenmüller, 2015). Many years of academic teaching and intensive practice may provide skills to the musician, but talent and creativity will be also necessary to build up virtuosity. Often, virtuosity refers to expert performance but not necessarily creative delivery of the music. Here we contrast "academic" giftedness (virtuosity) and giftedness as an original way to interpret a piece of music. According to Walberg (1988), talent is "*the outstanding mastery of systematically developed abilities, called competencies: knowledge and skills.*" Talent is also defined as the potential for achievement and the capacity to learn relevant material (Gardner, 1983, 2011).

Gagné's definition of talent and giftedness (1998) applied to music is: *"Musical talent is the demonstration of systematically developed abilities in the playing of a musical instrument at a level which places the individual among the top 10% of peers having similar training. Musical giftedness designates the possession and use of natural aptitudes in domains that influence the development of musical talent" (*Gagné & Blanchard, 2004). According to Sternberg & Lubart (1995) creativity is "*the ability to produce original work that fits with the context and responds to task constraints.*" Actually, talent and creativity are the main challenges for a virtuoso musician: he or she must be able to produce an original piece of music or classical piece of music in a unique way although this piece has been played by other musicians often hundreds of times. Each time a virtuoso musician faces a new piece to play, he or she has to deal with a new situation which requires active problem solving. One of the main problem solving concerns is fingering patterns.

The musician has to find the best fingering patterns to use. Musicians have acquired knowledge of fingering rules and procedures but also a procedural knowledge of a wide range of fingering patterns by doing technical exercises. These fingering patterns could be applied on similar note patterns in sight reading. However, sometimes the musicians can choose to use an unusual or uncomfortable fingering pattern if it allows him to intensify the musical expression of a passage (Gellrich & Parncut 1998). The best fingering depends also on the piece, the style, and the period. The musician must be able to make the most of his instrument in order to express shades and emotions, to translate musical language and context. Thus, the musician must be able to apply familiar situations, trained during thousands of hours of practice on an instrument, in new ways, with respect to the demands of the piece of music, in compliance with composer's intentions. He or she has actually to realize a production which is appropriate, i.e. adapted to the context, but which is new: original, unusual, and somewhat unexpected. Creativity will depend on many mental operations, but also on emotional (emotion, motivation, humor) and environmental factors.

Thus expert memory may explain inter-individual differences between virtuoso musicians who are able to play a well-known piece of music in their own way, using stored musical knowledge in a creative way. It is a real challenge for a musician to use the context to anticipate musical passages which are going to follow. The musician spends hours to practice scales and arpeggios so that he or she can easily recognize them during sight-reading. Also, the knowledge acquired concerning musical structures (harmony, counterpoint) allows musicians to use the context to anticipate the continuation of certain passages (Sloboda, 1978). In this time, concert pianists assert that atonal compositions are more difficult to memorize than tonal compositions doubtless because they cannot be guided by the rules of musical syntax (Miklaszewski, 1995). Indeed, musical improvisation in jazz music can be considered as a prototypical form of creative work in which long term working memory might be involved. As the use of natural language, the process of improvisation relies on mental processes that predicate new combinations of elements (harmonic, rhythmic) within a relevant context (Limb & Braun, 2008). During jazz performance, when musicians have to improvise a novel solo, they use the chord structure and the melody of a composition. Pierre Boulez said (2014, p.425): "*The improvisations are based on a vocabulary completely assimilated, but used above (or below) the cohesion.*"

Considering the memory performances of certain experts who can mobilize a huge quantity of information very quickly, theories of skilled memory propose that the individuals are capable of using a part of their long-term memory (LTM) as a working memory (WM), conceiving WM as a functional subset of the LTM which is represented to the cerebral level by all the neuronal connections (For a review, see Guida, Tardieu & Nicolas, 2008). By studying the impact of a mnemonic method for increasing memory span, Chase and Ericsson (1982) proposed a skilled memory theory. Their major theoretical point is: "*one important component of skilled performance is the rapid access of a sizable set of knowledge structures that have been stored in directly retrievable locations in long-term memory*" *(Chase & Ericsson, 1982, p.55). This skilled memory theory* is based on three principles: *significant encoding, retrieval structure and acceleration* that drive exceptional memory performance[33] and can explain how college students were able to increase their performance on a digit span task from 7 digits to over 80 digits, after extensive practice. 1) The *significant encoding* allows an individual to organize and encode the information to be learnt in a significant way: information is encoded into LTM in terms of prior knowledge. After building a huge base of knowledge, the individual relies on this prior knowledge to encode the presented items and store the items as encoded groups in LTM. 2) A separate LTM knowledge structure (a meta-structure), called a *retrieval structure* is used to keep track of the order in which the information was presented. Retrieval structures are hierarchically organized. The encoded information is linked by retrieval cues between the contents of short-term memory and a terminal node. These retrieval cues can later trigger retrieval from LTM. 3) encoding and retrieval speedup with practice: This *principle of acceleration* refers to increased performance and speed of memorization thanks to the training. Based on Chase and Ericsson (1981), most of the theories for expert memory have granted a crucial role to both the organization of the knowledge in memory and the retrieval structure (Ericsson & Staszewski, 1989; Ericsson and Kintsch,1995; Ericsson & Lehmann, 1996).

One of them, the Long-Term Working Memory theory (LTWM, Ericsson & Kintsch, 1995) is appropriate to explain how expert musicians manage the constraints of musical reading and execution with visible ease (Williamon & Valentine, 2002; Drai-Zerbib & Baccino, 2005). This theory is based on the three principles of Chase & Ericsson, but generalizes the retrieval structures in various domains: chess, medical diagnostic, problem resolution, computer programming, mental calculation, text comprehension, and music, and clarifies certain mechanisms. Three crucial points are underlined: 1) every activity shapes a type of retrieval structure, 2) the retrieval structure emerges from the interaction between the individual and the type of task, 3) for the expert, his LTWM is only usable in his or her specific field of expertise. Indeed, to perform some complex cognitive tasks, the necessary information to reach the goal has to remain available and easily accessible throughout the execution of these tasks. A high-level process can use the information stemming from a lower-level process if this information stays available for a minimum duration. This availability is possible thanks to specific processes in memory, called buffers, containing the results of intermediate processes. The memory creates buffers containing the results of the intermediate processes during a certain duration and there are complex processes at various levels of analysis, starting at the sensory level for every cognitive state. For example, during text reading/comprehension it is necessary to remember the objects and subjects mentioned to which the pronouns refer. In music reading, although the structure of the language is different, it is also necessary to maintain in memory the information related to the context in order to integrate each musical phrase in a coherent way. In classic theories of memory, these criteria of availability and accessibility are only gathered in working memory. Still, the classic definition of working memory is very restrictive: that is, the temporary storage for a short period of

[33] Exceptional memory performance being considered as acquiring encoding and retrieval skill without assuming exceptional capacity.

the information under process, without recovery or reactivation, regardless of the cognitive activity (Baddeley, 1986). So the capacity of this model of working memory is too limited to underlie the various mechanisms involved in expert reading. How does it work? LTWM is described as follows in the original article (Ericsson & Kintsch, 1995, p. 211)

> "…A general account of working memory has to include another mechanism based on skilled use of storage in long-term memory (LTM) that we refer to as long term working memory (LT-WM) in addition to the temporary storage of information that we refer to as short-term working memory (ST-WM). Information in LT-WM is stored in stable form, but reliable access to it may be maintained only temporarily by means of retrieval cues in ST-WM. Hence LT-WM is distinguished from ST-WM by the durability of the storage it provides and the need for sufficient retrieval cues in attention for access to information in LTM."

In other words, the theory of LTWM proposes that working memory is an activated part of the long term memory and a part of the LTM can be used as a working memory, through retrieval structures based on cues, which are the core of this theory. LTM is used as an extension of working memory, in high demanding specific domains and activities, after intensive training.

Two mechanisms are necessary in this LTWM theory: the short-term working memory mechanism (STWM) and the long term working memory mechanism (LTWM). The implementation of retrieval structures allows the use of a part of the LTM as working memory. The STWM is a working memory (WM) with a small contribution from the long term memory (LTM) providing an attentional focus of 3-5 items. The STWM maintains the information used as activated retrieval cues. Those cues are actionable according to the characteristics of the retrieval structure and allow information in LTM to be reached quickly and reliably. LTWM is the part of LTM which is accessible via the information in STWM. A single retrieval using a retrieval cue in STWM can make available the activated part of the LTM. Thus, the available items in STWM are retrieval cues capable of retrieving the part of the LTM which is connected to them by the retrieval structures. The first important point is that information in LTM stays accessible at the start and until the end of the processing thanks to the retrieval structures. Thus LTM is conceived as a storage center during processing. The second important point is that encoded information is stored in a stable way in LTWM and the access to this information is temporarily maintained by retrieval cues in STWM, though a certain quantity of retrieval cues is necessary to access to the information in LTM.

The LTWM theory includes two types of cue-based retrieval structures (Ericsson, & Kintsch, 1995, p. 220):

> "…cue-based retrieval without additional encodings and cue-based retrieval with an elaborated structure associating items from a given trial or context. The demands a given activity makes on working memory dictate which encoding method individuals are likely to choose so as to attain reliable and rapid storage and access of information in LT-WM. This encoding method, which is either a retrieval structure or an elaborated memory structure or a combination of the two determines the structure of the acquired memory skill."

Thus, items available in STWM become cues likely to retrieve the part of the LTM which is connected to them by retrieval structures. A cue in STWM can make available the active part of the LTM. The storage in LTWM is thus unlimited but specifically present in experts who are used to perform a given complex task. Moreover, retrieval structures are formatted according to the activity of expertise and can only be used in this activity. There is thus a wide spectrum of structures according to different needs inherent in a task. This diversity of retrieval structures is due to the fact that they are built in interaction with a type of task (Ericsson & Kintsch, 2000).

This theory is supported by studies in different domains (Guida & Tardieu, 2005; Kintsch & Mangalath, 2011; Drai-Zerbib & Baccino, 2014). Pesenti et al. (2001) contrasted with positron emission tomography (PET) complex mental calculation to memory retrieval of arithmetic facts of a young expert calculator (able to quickly and accurately solve complex mental calculations) compared to non-experts. They found (p 103) that:

> "an expert could switch between short-term effort-requiring storage strategies and highly efficient episodic memory encoding and retrieval, a process that was sustained by right prefrontal and medial temporal areas" and claimed (p 106):
> "the present neuroanatomical results thus, strongly support the theoretical framework of the Long-term working memory. We show that high-level expertise—here, calculation expertise—results in processes and brain activations not present in non-expert calculators. In addition, the use of long-term episodic mechanisms to expand the limitation of the short-term working memory partly accounts for high-level expertise."

In the domain of music, long term working memory theory can provide explanations about inter-individuals' differences in music reading and performance. This suggests that skill, talent and creativity might be largely a matter of using strategies to retrieve efficiently and recycle knowledge stored in memory. Tonal musical writing is driven by harmonic rules and codifications (Danhauser, 1996) that seem to belong to retrieval mechanisms described above (Williamon & Valentine, 2002; Drai-Zerbib & Baccino, 2014). Empirical studies have observed classical concert pianists preparing their musical performance; a concert pianist uses the musical structure to organize the performance and memorize a new piece of music in only a few hours of training (Chaffin, 2006; Chaffin and Imreh, 1997). The pianist relied on cues to insure information retrieval in LTM. In this case, she organized her performance according to the formal structure of the piece, compared the various themes and observed their repetitions. She stopped at the end of each musical phrase rather than in the middle of a section. Furthermore, most of the time, musicians have to memorize the piece of music they will have to play in concert. Whereas non-experts learn the piece by heart, classical concert pianists analyze the musical score in detail, writing observations about the musical elements (Aiello, 2001). Expert musicians are able to use hierarchical retrieval mechanisms to recall encoded information (Halpern & Bower, 1982; Aiello, 2001; Williamon & Valentine, 2002). They are able to index and categorize musical information in meaningful units (Halpern & Bower, 1982) which they use later when practicing or during a performance (Williamon & Valentine, 2002). Conceptual knowledge such as tonality and musical genre may be stored in memory as schemas (Shevy, 2008).

Moreover, music reading relies on cross-modal competencies. At least three different modalities are involved: vision, audition, and motor competencies are linked by knowledge of the musical structure if available in memory. While reading without listening to Bach's Sonata in trio, an expert musician is able to find out and hierarchize the different musical elements (musical form, thematic parts, dynamics, rhythm, harmony). This ability to hear music from the score was pointed out by the composer R. Schumann (1848), who advised his young students to sing at first sight a score without playing piano, and to train hearing music from the score in order to become an expert in music. If expert musicians can hear what they read from a score and represent visually the music that they are listening to, in cognitive terms, this means that an expert memory has been put into place during the years of practice. This expert memory facilitates the shift between vision and audition, and mixes both of them compared to non-expert who would separate the two types of processing. Indeed, the underlying processes in musical reading consist in extracting the visual information from the musical score, interpreting the musical structure, and performing the score by simultaneous motor responses in playing or singing, relying on an auditory feedback. As in all complex activities, expertise in musical reading is heavily related to multisensory integration which depends on individual expertise. Research on eye movements has highlighted inter-individual differences in music reading related to expertise (Drai-Zerbib, Baccino, Bigand, 2012; Drai-Zerbib & Baccino, 2014). More-skilled musicians show very low sensitivity to the written form of the score and are able to reactivate quickly a representation of the musical passage from the material previously listened to. In contrast, less-skilled musicians are very dependent on the written code and on the input modality of information. They have to build a new representation based on visual cues (Drai-Zerbib & Baccino, 2005) which can be illustrated in the different visual strategies in Figure 1 below.

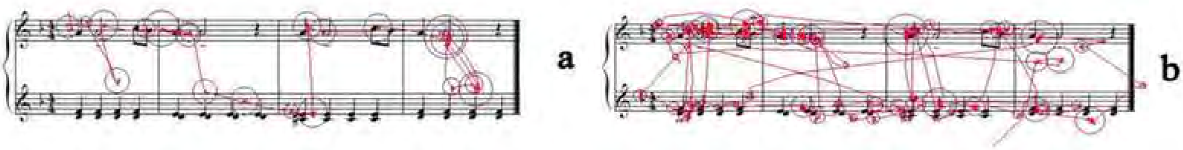

Figure 1: Experts (a) and non-experts (b). Eye movements (fixation strategies) while reading the same musical fragment.

This relative independence of experts from the score is also verified when fingering is not adapted to execution (fingering helps to anticipate by providing visuo-motor cues): experts ignore difficult fingerings annotated on the score when they have previously listened to the musical fragment, probably because they have stored the musical information in memory whatever the input source was. Conversely, less expert musicians process and apply perceptual cues even if they are not adapted for the performance (Drai-Zerbib, Baccino, & Bigand, 2012). Moreover, when expert and non-expert musicians have to retrieve a modified note between the listened music and the read music, an accent mark (a specific musical cue contributing to the prosody of the phrase), placed in a coherent or incoherent way, appears for non-experts as interference leading them to incorrect judgments (Drai-Zerbib & Baccino, 2014). So, musical knowledge supposed to be stored as retrieval structure, can be accessed very quickly from musical cues (Drai-Zerbib & Baccino, 2005; Ericsson & Kintsch, 1995; Williamon & Egner, 2004; Williamon & Valentine, 2002b). The important point is that some perceptual cues might be less important for experts because they are capable of using their musical knowledge to compensate for missing (Drai-Zerbib & Baccino, 2005) or incorrect information (Sloboda, 1984). The LTWM theory can explain differences of strategies between experts and non-experts. Tonality, phrasing and accent marks, belong to harmonic rules. These harmonic rules, represented as retrieval structures, are well grounded in the expert musician and allow individuals more efficient processing. These structures of musical knowledge are acquired with the intensive practice of music. In summary, it appears that the musical brain uses musical codes stored in memory using specialized retrieval strategies. Even in atonal music, composition relies on codifications. The composer Pierre Boulez said (2014, p. 125-126):

> "There are only codes that are artificial and that we understand more and more difficultly as one moves away…The tonal phenomenon is based on certain constants; on what I call the polarization phenomena. In the tonal world, these are clearly established in one key elements and then we module and we move into another well-established tone. Balance, unbalance, balance. The non-tonal world is exactly the same. There are points of equilibrium which may be polarized, for example, around some notes, some arrangements. Then comes a time when we may well unbalance, a very anarchic moment then returns to other types of polarization."

Conclusion

The very interesting question concerning skill, talent and creativity in music is a question of inter-individual differences pointing out how people use different strategies to encode, retrieve and recycle knowledge in memory. This is also a crucial question for musical teaching that might enhance individuals' creativity to capitalize on the base of knowledge stored in memory to build an expert memory, but also the necessity of deliberate practice which participates in the construction of musical expertise. A huge field of research concerning creativity and music comprehension, execution or composition has to be further investigated and innovative methods of talent identification should be developed. For example, we attempted recently to develop an objective indicator of musical reading expertise to classify musicians from their visual performances (eye movements), carried out while reading musical scores. The study (Baccino & Drai-Zerbib, 2015) used advanced multivariate pattern analysis (MVPA) to determine whether musical reading was encoded in the eye-movement features (fixation duration, saccade amplitude, pupil dilation). MVPA has been used successfully in cognitive neuroscience to infer the content of representations encoded in patterns of cortical activity from functional neuroimaging data (O'Toole et al., 2007). It has also been successfully applied to eye-movement data to classify the viewer and the visual stimulus (Greene, Liu, & Wolfe, 2012) or the task (Henderson, Shinkareva, Wang, Luke, & Olejarczyk, 2013). Applying MVPA here uses the same logic to investigate whether the eye-movement record contains sufficient information to permit inferences about the musical reading that a person is engaged in, and by extension, to her underlying expertise.

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