A matter of perspective

Andrei Pogorilowski

I – THE STARTING POINT

The moment two isochronous tempi…

(1) …within a temporal scope familiar to musical practice and to functional perception/production of discrete time (e.g. IOI between *(Michon, 1964)* ≈ 100 and ≈ 700ms);

(2) …whose pulsations have perceptually different IOI values. (In principle, the difference between the two IOIs should equate or be bigger than the +/- 5% specific to the Weber fraction – which, nota bene, is *not* a universally valid constant for temporal discrimination – or overpass the perceptual threshold of the just noticeable difference (JND) that varies between +/-4% and +/-9%, depending on the specific context *(Levitin & Cook, 1996);*

…follow each other, the theoretical interpretation of the passage from the first isochronous tempo to the second and of the relationship thus established between the two tempi can be done in two +1 ways:

(a) durationally (i.e. rhythmically)
(b) perceptually in a cognitive mode and, in some cases,
(a,b +1) durationally/perceptually in an impressionistic mode

In the first case (a), things appear to be quite simple. If the two IOI values find the least common multiple or a common denominator within the simple arithmetic of the classical rhythmical system, the durational perspective is served without further complications. In the case of the temporal scope chosen for illustration in this study, the „simple arithmetic" stretches from the 1:7 (or 7:1) ratios up to 6:7 (or 7:6), passing through all the possible permutational variants involving figures from 1 to 7 and including other ratios that are commonplace for musical practice, such as 1:1.5 – e.g. crotchet-dotted crotchet etc.

There are two reasons why I have chosen this temporal scope (i.e. IOI from 100ms up to 700ms):

(1) in the case of the 1:7 ratio (e.g. an IOI made of crotchets + an IOI made of corresponding septuplets), we shall reach a limit of the IOI values chosen for illustration, the crotchets having to last for 700ms each and the notes making the septuplet – 100ms each.

(2) those who have studied the relationship between the quantity of information vs. timespan *(Fraisse, 1937, 1964; Ornstein, 1969)* have established that humans in general cannot operate properly, within a single unit of perceptual present, with more than 6-7 elements.

This is why, a 1:8 (or 8:1) ratio, although easy to represent rhythmically as a relationship between an isochronous tempo made of, say, crotchets vs. one made of demisemiquavers (or viceversa) – would make either (1) the faster tempo be made of IOI values shorter than 100ms (i.e. 700ms ÷ 8 = 87,5ms) or (2) the slower tempo be made of IOI values larger than 700ms (i.e. 100ms x 8 = 800ms) or, if we accept this enhancement of the temporal scope chosen for illustration in this study, the number of stimuli relating durationally to the 700ms (or 800ms, v. supra) integer (3) would exceed the critical amount of 6-7 elements, the eight pulsations being more likely discriminated perceptually as a pattern made of two groups of four rather than one group of eight. But this is another discussion.

On the other hand, 700ms represents, as an IOI value, an ideal unit of perceptual present, its duration being called by Fraisse *(1964)* „a psychic constant corresponding to the duration of the complete process of perception". To be precise, Fraisse had referred to 750ms – but both IOI values (i.e. 700ms and 750ms) represent well a perceptual threshold copiously studied by experimental psychology and other related disciplines.

It is important to take note that in this case (a) the two isochronous tempi have been construed from a durational-relational perspective by means of the theoretical apparatus provided by the rhythmical system.

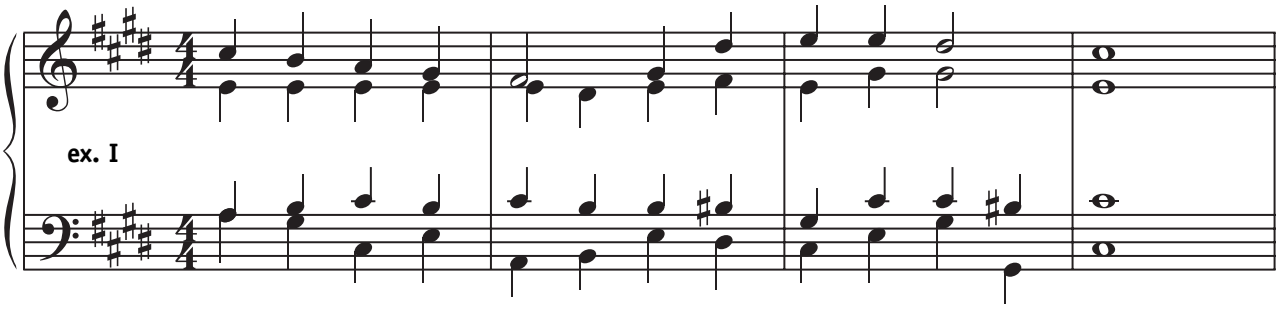
In the third case (a +1), we may encounter the following two situations:

(x) the two isochronous tempi create a, say, 6:7 durational ratio but they are being interpreted as a single isochronous tempo that „gets animated" at a certain point by means of a movement indication such as *più mosso* or *più animato*. Conversely, the same thing may happen with a 7:5 durational ratio, the movement indication being in this case something like *meno mosso;*

(y) the two isochronous tempi create a durational relationship that escapes the „simple arithmetic" mentioned earlier. For instance, let us suppose that the two tempi create a 3:5.3 durational ratio – one example among many other possible. One way to construe this situation is to see the relationship established between the two isochronous tempi as a 3:5 ratio – e.g. triplets vs. quintuplets – the latter being marked, as in the (x) situation, with a *più mosso* indication.

II – A BRIEF JOURNEY TO THE HARMONIC HEARING

Let us consider the following harmonic progression (ex. I) taken over, with a few modifications, from the Matthäus-Passion chorale „Erkenne mich, mein Hüter" by J. S. Bach. Musicians should reminisce the period when they had trained somewhat their intervallic, but not yet the harmonic hearing – a period when elogizing such a musical excerpt meant, both horizontally and vertically, an effort to imagine pitch intervals. Personally, I remember how, years ago, a diminished fifth meant to me the effort to elogize a perfect fifth and then to step back one semitone. Similarly, in order to represent mentally any chord, I used to elogize first the bass note and then add successively the upper intervals (e.g. the first chord in ex. I: A-E and then E-$C^{\#}$). In other words, music novices are first confined to a wholly intervallic perspective over pitches that – as it usually doesn't allow for a horizontal-real-time and a vertical-simultaneous elogization – becomes a reason for frustrations and an incentive for improvement.

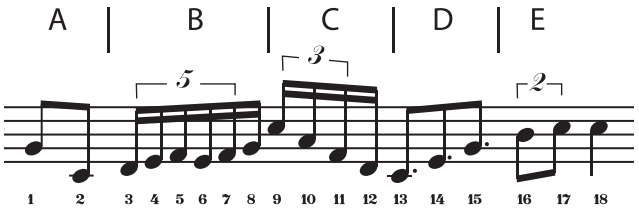


It is important to note here that once the harmonic hearing is reasonably formed, a musical piece such as the Bach chorale simply „sounds" in our heads when we read a score, while the intervallic-relational approach that characterized our novitiate seems to have vanished from our elogization strategies (at least for harmonic progressions well rooted in the tonal system). The cognitive and mnemonic mechanisms that lead to our capacity to elogize musical scores won't be further discussed in this study.

III – BACK TO TEMPI

Assimilating the bar-rhythmical system produces much less frustrations from this point of view. Except for a few well known „shibboleths" such as syncopations, contratempi, polymeters and polyrhythms, various uncanny and unwieldy tuplets etc. – real-time elogization of the classical bar-rhythmical structures takes us relatively little time to master, both horizontally and vertically (e.g. the case of conductors or pianists etc.). The necessity to foot-tap the taktus or to rely on the tick-tocks of a metronome in order to maintain a unswerving tempo and to organize a rhythmical surface is one of the first „victims" produced by music novices. However, that doesn't mean that – in this case and in comparison to the intervallic perspective described in Section II – the durational/relational perspective vanishes completely once with the assimilation of the bar-rhythmical system, for it is just put to a subliminal (and shallow) sleep by the metrical organization. Here is a counterexample (ex. II):

ex. II



In this example we deal with a non-metrical rhythmical surface. The ametrism primarily stems from the fact that the 18 pulsations are not organized around a singular pulse.

Nota bene, the tuplets in this weird example must be read *only* in relationship to the preceding isochronous tempo and not to an integral duration. That is, 5 notes from the quintuplet *do not* equate in this example 3 notes from the triplet as they create here a 2:3 (not a 5:3) ratio (i.e. 2 pulsations from the quintuplet = 3 pulsations from the triplet).

All in all, there are in ex. II five isochronous tempi (A—1-2, B—3-8, C—9-12, D—13-15 and E—16-17) establishing the following durational relationships:

A:B = 2:5
B:C = 2:3
C:D = 3:1
D:E = 3:2

If we convene that a crotchet at the beginning of the example lasts for 1400ms, the five isochronous tempi will have the following durational values for each pulsation:

1-2	= 700.0ms	rounded off	(A) = IOI 700ms
3-8	= 280.0ms		(B) = IOI 280ms
9-12	= 186.6ms		(C) = IOI 187ms
13-15	= 559.8ms		(D) = IOI 560ms
16-17	= 839.7ms		(E) = IOI 840ms

What is interesting with this example is the fact that although the five isochronous tempi perfectly obey the „simple arithmetic" mentioned in Section I (i.e. 2:5, 2:3, 3:1 and 3:2 ratios), a first-sight/real-time elogization (or musical performance) of the 18 durations seems to be quite tricky. The lack of a unifying metrical frame makes the durational-relational perspective become extremely important here, as it is woken up from the subliminal sleep in which we expected it to rest. However, the reasons why we find it difficult to first-sight elogize the rhythmical surface in ex. II won't be a topic in this study.

IV – THE PERCEPTUAL PERSPECTIVE – FIRST ATTEMPTS

Let us now suppose that ex. II is a violin part with a G clef placed at the beginning of the staff, written by a contemporary composer and that we are a violinist who has to perform it tomorrow in a concert. If time presses and a durational perspective seems to poise so many problems, we might consider the perceptual perspective mentioned at the beginning of this study. For instance, we may set a computer to reproduce the 18 durations in ex. II and then listen to them countless times until we consider ourselves capable to perform them in synchrony with the computer and, finally, independently. Probably that won't be what the composer wanted from us but, given the circumstances, we can say that we did what we could.

Another solution would be to place the five isochronous tempi in a certain order (e.g. fastest to slowest), listen to them separately, in different melodic contexts and countless times – thus memorizing them and educating our perception to distinguish them well.

tempo 01 – (C) = IOI 187ms (MM = 320 bpm)
„the «fast» isochronous tempo"

tempo 02 – (B) = IOI 280ms (MM = 214 bpm)
„the «medium-fast» isochronous tempo"

tempo 03 – (D) = IOI 560ms (MM = 107 bpm)
„the «medium» isochronous tempo"

tempo 04 – (A) = IOI 700ms (MM = 86 bpm)
„the «medium-slow» isochronous tempo"

tempo 05 – (E) = IOI 840ms (MM = 71 beats per minute)
„the «slow» isochronous tempo"

After that we should be able to reproduce the five tempi from memory – something that shouldn't poise too many problems as long as we accept deviations that do not exceed the JND and Weber percentages (cf. supra, Section I). The scholars who studied the existence of an „absolute temporal hearing" *(Halpern, 1992; Collier & Collier, 1994* plus the whole literature dedicated to the accuracy of „internal clocks" – e.g. *Gilden, Thornton, & Mallon, 1995; Helmuth & Ivry, 1995)* have demonstrated that even randomly chosen subjects can reproduce tempi – *that they didn't even propose themselves to memorize* – with a +/-8% accuracy, in 72% of the attempts *(Levitin & Cook, 1996)*.

Finally, we should learn to switch (by elogization or instrumental performance) from one thus memorized tempo to another – that giving us the opportunity to perform the pulsatory surface of ex. II from a perceptual perspective:

(A) tempo 04, isochronous, «medium-slow» 2 pulsations
(B) tempo 02, isochronous, «medium-fast» 6 pulsations
(C) tempo 01, isochronous, «fast» 4 pulsations
(D) tempo 03, isochronous, «medium» 3 pulsations
(E) tempo 05, isochronous, «slow» 2 pulsations

The idea of „perceptual perspective" means here that we shall link the first 17 pulsations, grouped in five categories of isochronous tempi, without relating them durationally – as the case was with the rhythmical approach. We shall simply combine the five memorized isochronous tempi in the proper order (see ex. II) – the only inevitable durational relationship being the 1:1 ratio, established between the pulsations of any of the five tempi.

V – A PERSONAL EXPERIENCE

Long before having read the first study dedicated to internal clocks accuracy or to the existence of an absolute temporal hearing I used to play around juxtaposing on my piano short passages (3-4 bars) from the few dozen musical compositions I then happened to know by heart – without a break and in each excerpt's original tempo. I was amazed by the fact that I thus instantly passed from one tempo to another without having any idea whether they established or not one of the „simple arithmetic" ratios specific to rhythm theory. Then I wondered whether I could memorize a sufficient number of isochronous tempi, from „very fast" to „very slow" – that I could recognize anytime I hear and produce whenever I want, one at a time or in different successions. Thus, a first pathway towards a perceptual vision over musical time – different from the bar-rhythmical approach – had been opened.

VI – SECTION IV WAS JUST A GAME

Of course it was just a game. It was as if we had to teach – quickly! – a musical profane to recognize five musical intervals…

01 – the major second = „the «short» interval"
02 – the major third = „the «medium-short» interval"
03 – the perfect fifth = „the «medium» interval"
04 – the major sixth = „the «medium-long» interval"
05 – the octave = „the «long» interval"

…in order to make him or her combine them afterwards in any imaginable order. Well, even if our novice brings this game to the end, he or she won't be able to consider himself/herself initiated in classical music theory because essential terms such as tonality, consonance, modulation, chromaticism, diatonism etc., etc. – plus all the functional nature of verticalized pitches that make the beauty of the tonal dodecaphonic system – will remain alien to him or her. *Mutatis mutandis,* the very same thing can be said about memorizing the five isochronous tempi defined in Section IV. In the next Section we shall muster a part of the terminology and musical universe that we missed by accepting this temporal game.

VII – HOW MANY (CATEGORIES OF) ISOCHRONOUS TEMPI DO WE HAVE?

The hypothetical question „how many intervals within an octave should we discern so that the resulting choice be neither too simplistic nor too unwieldy for musical practice?" appears to have been answered by Western music in a definite way: twelve intervals (including the octave itself and excluding the perfect prime). Whether the question (thus put) ever existed in the minds of Western musicians, how many stages and how much time it took for this answer to be given – all that won't be a subject of debate here. The fact is that the number of musically used intervals could have been 5 (like in pentatonic scales), 7 (like in the diatonic modal systems) or even 22 (like the *shrutis* of *râga* music). Whether „twelve" is a good, simplistic or too complex answer – again, that won't be discussed here. The fact remains that the Western musical community largely takes this answer for granted.

The hypothetical question „how many isochronous tempi within the workable temporal scope (i.e. IOI between ≈ 100-1500ms – cf. *Bolton, 1894)* should we discern so that the resulting choice be neither too simplistic nor too unwieldy for musical practice?" seems to have been never answered by musicians as the durational (i.e. bar rhythmical) perspective over musical time made irrelevant (at least in the Western hemisphere) the mere existence of such a question. For many years, the answer seemed to have been: „we can discern as many isochronous tempi as we can relate durationally to a given IOI value". To my knowledge, nobody wondered seriously how many isochronous tempi (or at least

categories of isochronous tempi) we can discern *ad absolutum* until cognitive psychology, psychophysics, the brain sciences and experimental psychology started to intersect musical time theory.

The naive (yet just) answer to this question would be: three categories – „slow, medium and fast tempi".

The minimal answer would be: „as many isochronous tempi as the number of scientifically established perceptual thresholds within the temporal scope (cf. supra)". Let us briefly muster some of these thresholds:

01 – the threshold between the estimation vs. perception of the very isochronicity of an isochronous tempo and the threshold of the perceptual integration of two stimuli *(Pöppel, 1972; Michon, 1978; Fraisse, 1982)* – around 1500ms;
02 – the threshold whence we start to experience durations-as-such and temporal gaps *(Fraisse, 1964)* – around 700ms;
03 – the threshold of human resonance at the level of the central nervous system *(van Noorden & Moelants, 1999)* – around 500ms;
04 – the threshold between the holistic vs. analytical processing of durations *(Michon, 1964)* – around 250ms.
05 – the threshold of Gestalt-type integration of consecutive pulsations, of the minimum acton *(Clynes, 1989)* and of the minimum duration of the perceptual present *(Pöppel, 1988)* – around 200ms;
06 – the threshold of the minimum duration that allows for cortical processing of stimuli *(Roederer, 1995)* and the threshold of subjective rhythmization *(Bolton, 1894)* – around 100ms.

Other thresholds may be added to this incomplete list. However, in completing it I discarded other defining characteristics of each of the six thresholds. Thus, I did not mention the indifference interval, the different behavior (from one threshold to another) of the just noticeable difference, of the subjective rhythmization or of subjective accentuation. Similarly, I did not refer to pulsatory inertia and entrainment, the optimal rate of attention shift, the preferred tempo – or to many other similar things. More so, I reduced the list of scholars who have contributed to the definition of these thresholds to an illustrative minimum. Finally, I have marked each threshold with a single IOI value (expressed in milliseconds), although some of these thresholds have large „bandwidths" that are hard to average.

The maximal answer to the question would be „as many isochronous tempi as the Weber fraction and the JND mechanisms allow for within the temporal scope (cf. supra)". Thus, if we accepted that a 5% difference between consecutive IOI values would be universally sufficient (which is not) for perceptual tempo discrimination, we would deal with an impressive number of 57 theoretically discernible isochronous tempi between IOI 100 and 1500ms (1533ms, to be precise) – which sounds very unlikely.

One of the major challenges for music theorists in the near future will be to establish the sufficient and reasonable number of discernible tempi within the (musically) workable temporal scope – an accomplishment that, in my opinion, cannot be but the result of a collective effort. Simultaneously, all these tempi will be allotted to the various temporal thresholds.

VIII – A BIT OF CRITICISM WON'T HARM ANYONE

The essential question that we should poise ourselves whenever we want to single out a certain isochronous tempo is „what do we feel?" – „what do we experience when we perceive/produce an isochronous tempo?". In order to give a professional answer to this question, musicians are bound to master the terminology partially mustered along the previous Section.
The experiments that defined the perceptual thresholds did not always take this question into consideration. For instance, let us think of the indifference interval: although it marks such a threshold, it answers a different type of question. The subjects who helped this threshold be discovered did not have to answer the senseless question „around which tempo do you experience that you neither quicken nor slack down the tempo you have to reproduce?". On the other hand, since categorizing thresholds is to probe one's perception, the question „what do you experience?" was always present and the answers, although given in lab circumstances, help us respond to it in a better way.

Defining perceptual thresholds in IOI values (expressed in milliseconds) is a good and necessary thing especially for the work of psychophysicists and experimental psychologists. Their results *must* produce the most accurate data possible. Despite that, and as a personal opinion, I think that allotting perceptual thresholds to precise IOI values (the obsession for *accuracy – Ornstein, 1969)* is not as useful for those musicians who want to assimilate a large and yet flexible picture of temporal perception. Their aims would be better served if, on the one hand, they will know in detail the perception phenomena (and production epiphenomena) related to discrete time – *as such* and the precise order in which all these appear, from IOI 20-40ms to IOI 5000-7000ms. This span represents the wider spectrum of musically relevant temporal perception, from the discrimination threshold of two consecutive stimuli *(Hirsch, 1959)* and the temporal order threshold (i.e. 30-40ms, *Pöppel, 1988)* to the maximum span of attention *(Pöppel, 1972; Michon, 1978 et al.)*. On the other hand, the most important thing for musicians would be to „feel" all these perceptual phenomena whenever they interact with various durations, isochronous tempi and other temporally discrete structures. That would surely lead to a proper education of the temporal hearing, whereas just memorizing millisecond-defined IOI values corresponding to perception phenomena would only bridge a theoretical view over musical time.
Balancing the accent from experimental psychology and cognitive musicology towards an organically assimilated musical time theory can only be done by stressing the importance of educated temporal perception. If not, we risk to reach more and more often to contextually just conclusions that will turn out to be wrong once submitted to a more delved-in perspective: 1000 randomly chosen subjects asked to hand-walk on a tightened rope (to swallow swords or to juggle with 5 torches…) in the frame of an experiment will probably make the researchers reach to the conclusion that humans cannot do such things – whereas 1000 acrobats and

jugglers will debate over a completely different array of topics. *This* can become the difference between the preoccupations of cognitive musicologists and of those whose own educated temporal perception constituted a major priority. The criticism mentioned in the title of this Section pertained to the fact that the experimental era in temporal perception research seems unable to offer its results to the formation of a musico-temporal *language* capable to match in both complexity and scope the tonal harmony system, to make just the most relevant comparison.

IX – BACK TO THE FIVE ISOCHRONOUS EXAMPLES IN EX. II

Letting musicians find the „magical number" hinted at at the end of Section VIII, let's get back to our violin and to the five tempi described in Section IV, as we still have to get to a (non-jocular) perceptual perspective over the rhythmical surface of ex. II.

tempo 01 – (C) = IOI 187ms (MM = 320 bpm)
„the «fast» isochronous tempo"

tempo 02 – (B) = IOI 280ms (MM = 214 bpm)
„the «medium-fast» isochronous tempo"

tempo 03 – (D) = IOI 560ms (MM = 107 bpm)
„the «medium» isochronous tempo"

tempo 04 – (A) = IOI 700ms (MM = 86 bpm)
„the «medium-slow» isochronous tempo"

tempo 05 – (E) = IOI 840ms (MM = 71 beats per minute)
„the «slow» isochronous tempo"

In order to reach to a professional perceptual perspective over the five isochronous tempi, we will study them one at a time, starting from the simple question mentioned in Section VIII – „What do I experience?" – and trying to answer it by means of a diverse array of theoretical methods (both direct and indirect), in order to better outline the peculiarities of the perceptual approach to musical time.

tempo 01 – (C) = IOI 187ms
According to Clynes *(1989)* once our brain orders the performance of the first two pulsations of a temporally-discrete structure in this isochronous tempo, we cannot change our mind while fulfilling this order. Once our brain launches a simple motor command and it started being executed, we cannot U-turn it during the first 200ms (the minimum duration of an acton). We can verify this psychophysical phenomenon by performing the first two pulsations of an isochronous tempo that is twice as slow (IOI 374ms), in which case we shall notice experientially that the two do not integrate anymore in a holistic structure and, as a consequence, *we can* change our minds (see supra), just because in this augmented context our brain can process pulsations separately (i.e. analytically).

The next step would be to chose faster and faster tempi (i.e. from IOI 374ms up to 187ms) and to propose ourselves to experience the threshold whence Clynesian mind-changing starts to seem impossible. Once reaching the first isochronous tempo whose first two pulsations create a holistic relationship (IOI ≈ 250ms), we can compare it to our tempo (i.e. IOI = 187ms), that should be faster. We shall have reached now the threshold between holistic versus analytical processing of durations *(Michon, 1964)*. What is interesting here is the fact that this isochronous tempo (IOI ≈ 250ms), although the first to impose a holistic perception over consecutive durations (two in our case), does not belong to the area in which the above mentioned mind-changing is not possible.

By continuing to experience even faster isochronous tempi we shall finally reach to the one that will be surely defined by the psychophysical phenomenon described by Clynes, that is, the impossibility to change our minds once our brain has ordered the production of two consecutive pulsations, *while* we produce them. By comparing this isochronous tempo to tempo 01 in ex. II we shouldn't notice a perceptible difference between the two. If the Weber fraction in this area (i.e. IOI = 187ms) were 5%, then only a IOI 196ms (i.e. 187ms + 5%) tempo would be the first perceptually discernible. But, according to a series of experiments in this direction *(Mach, 1865; Getty, 1975)*, the Weber fraction rises considerably for IOI values under 250ms – and, in consequence, we may say that our tempo (i.e. IOI = 187ms) can be well defined as representing „the first isochronous tempo between whose consecutive pulsations there exists a relationship specific to the minimum duration of an acton". That is, the first isochronous tempo whose holistic processing is also backed up by the impossibility to change our minds once we started to produce not one, but *two* pulsations.

There are *many* other ways to pinpoint experientially this isochronous tempo but it is not here the place for an exhaustive approach towards the ways IOI ≈ 187ms can be discerned perceptually in comparison to both faster and slower neighboring tempi. The point is that, by different exercises (and the quest for the threshold of the Clynesian mind-changing *is* such and exercise) we shall be able to develop an absolute memory for this category of isochronous tempo.

tempo 02 – (B) = IOI 280ms
As long as the threshold *between* the holistic and the analytical processing of successive pulsations lies somewhere around IOI 250ms, it means that in the very heart of this threshold things are quite ambiguous – the corresponding isochronous tempo being too slow to be defined experientially as belonging to the „holistic type" and too fast to be defined as belonging to the „analytical type". Fraisse *(1982)* mentions the IOI = 300ms value as the first one in which we experience without doubt durations as such. On the other hand there are in music beat-specific durations that Fraisse places between IOI 300-900ms, with an optimal 600ms IOI value (specific to the preferred tempo). Other scholars share different views. London *(2004)* considers that we can perceive a beat made of even shorter values (IOI 200-250ms) whenever we deal with simple divisions (i.e. 1:2) and that the IOI 300ms value as the minimum threshold for beat perception is valid only for compound structures (i.e. 1:3). In order to avoid furthering this debate, let us agree with both Fraisse and London and try to experience „the fastest compound tempo" by producing, first, an isochronous tempo twice as slow (i.e. IOI = 200ms), grouping its pulsations in chunks of three and, metrically, as a 12/8 bar (♪. = 200ms):

ex. III etc.

Unskilled instrumentalists may organize this experiment by means of a MIDI-compatible program (e.g. Finale, Sibelius, Score etc.). We shall then diminish the IOI value (♪ from 200ms to 100ms) until we shall experience perceptually the last isochronous tempo thus organized (see supra), in which we can still organize subjectively pulsations in groups of three. Theoretically, we should experience this threshold around ♪ IOI ≈ 100ms. Hence we can extract the beat tempo (i.e. *beat rate* ≈ 300ms) that we shall compare to tempo II (B) in ex. II – which should be a little bit faster than the JND fraction that, theoretically, for these values, corresponds to the 5% Weber fraction (i.e. 300ms – 5% = 285ms).

By repeating several times this experiment, in time we shall manage to develop an absolute memory of the Londonian tempo (i.e. „the minimum beat for compound tempi"), so that we shall be able to notice too, upon listening, a tempo that is just noticeably faster – which fact will fix in our memory the isochronous tempo 02 in ex. II too.

Of course, other, more direct methods to pinpoint experientially this tempo may be devised. I have chosen here a more intricate way to define a tempo for memory just because I wanted to suggest that assimilating isochronous tempi works better when they are studied, from a perceptual point of view, not just in themselves, but also in various contexts.

tempo 03 – (D) = IOI 560ms

Different studies dedicated to topics such as „preferred" or „spontaneous tempo" produced various results. A comprehensive example in this respect is Leon van Noorden & Dirk Moelants *(1999)*. The two musicologists compiled a huge amount of data, including baroque, polyphonic, romantic, jazz music, radio broadcasts, dance music and bpm charts. A peak of the most used tempi lies somewhere around the 500-550ms BR (beat rate). The conclusion of the mentioned study is that our central nervous system resonates whenever we interact with a musical pulse situated between 450 and 600ms BR. As a working solution, we can establish within this temporal scope four IOI values: 450, 500, 550 and 600ms. It just happens that it is around these values that we can speak of IOI values between which a particular perceptual discrimination relationship gets established – that is, the +5% Weber fraction of any faster tempo corresponds (as a newly estblished IOI value) to the -%5 Weber fraction of the next slower tempo:

450ms + 5% = 472.5ms
500ms - 5% = 475.0ms

Perceptually, the difference between 472.5ms and 475ms (i.e. 2.5ms) is absolutely negligible.

According to Mach *(1965)*, after the 535ms IOI value, the Weber fraction rises up to 6%, reaching 7% around IOI = 1000ms. Therefore, as far as Mach's discovery is valid (other studies say different things), the next comparisons will take into account his results:

500ms + 5% = 525ms
550ms - 6% = 517ms

550ms + 6% = 583ms
600ms - 6% = 564ms

Again, perceptually, the differences between 525ms and 517ms (i.e. 8ms) and between 583ms and 564ms (i.e. 19ms) are all but negligible.

Precisely because they are so common to musical practice (as beat rates) and because they lay, within the temporal scope, at perceptually well discernible intervals (i.e. approximately twice the Weber fraction), the four IOI values can be memorized as such – for instance by setting a metronome to render them (i.e. MM = 133, 120, 109 and 100bpm). That is definitely not a professional way to memorize isochronous tempi but, as far as IOIs larger than 500ms are concerned, it leads to good results. Once the four tempi entered our aperceptual background, we shall easily discern intermediary IOI values. In perceptual psychology, once the attributes of a series of consecutive stimuli (e.g. stimuli A, B, C, and D, sufficiently distanced – Weber fraction x 2) entered our memory, they can surely be discerned intermediary values that may be subjected to a taxonomy like this:

- (stimulus A)
- stimulus A^+
- stimulus A^+ or B^- (or between A and B)
- stimulus B^-
- (stimulus B)
- stimulus B^+
- stimulus B^+ or C^- (or between B and C)
- stimulus C^-
- (stimulus C)
- stimulus C^+
- stimulus C^+ or D^- (or between C and D)
- stimulus D^-
- (stimulus D) etc.

Important in this case is not the accuracy of intermediary stimuli perception (depending on the acuity of our educated temporal hearing, we may for instance mistake a A^+ stimulus for a B^- or a B stimulus for a B^- or B^+), but the very fact that we perceive certain stimuli as intermediary and that never shall we mistake the four main memorized stimuli between them.

Roughly the same thing may be said about the four memorized IOI values (i.e. 450, 500, 550 and 600ms). Perceptually, tempo 03 (D) in ex. II (IOI = 560) fits well the memorized isochronous tempo IOI = 550ms. As far as we shall be able to perceive somehow the +10ms difference, that is fine (although highly improbable) – it means that we may categorize this tempo as IOI 550^+.

tempo 04 – (A) = IOI 700ms

Fraisse *(1964)* considers that isochronous tempi between IOI 600-700ms are made of pulsations that, experientially, seem to follow each other like a series of objects of perception that neither overlap, nor create temporal gaps. Whereas

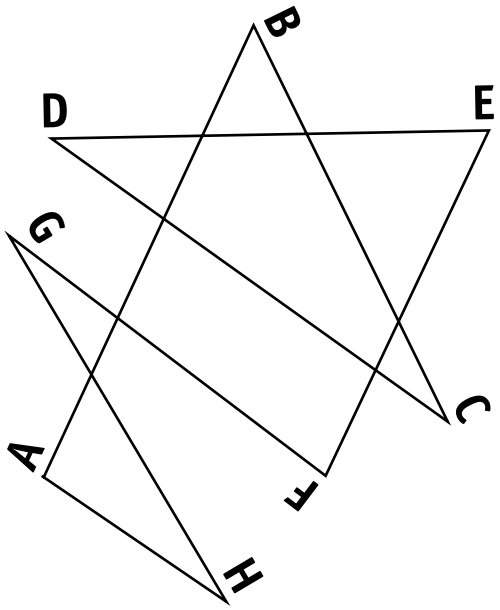
the optimal rate of attention shift lies somewhere around 600ms, *(Mager, 1925)*, the IOI = 700ms corresponds to „the central tendency for habitually perceived durations" *(Fraisse, 1964)*. Moreover, Wundt *(1911)* studied the natural durations for associations between two consecutive perceptions and established an 720ms average *(cf. Fraisse, 1964)*. There are numerous experiments to back up these assertions. For instance, subjects asked to reproduce a sound signal generally start to reproduce it 700ms after the signal having stopped *(Oléron, 1952)*. Likewise *(Fraisse, 1964)*, subjects asked to produce groups of three or four equal durations have spontaneously separated these groups with 600-700ms long pauses.
IOI values larger than 700ms are characterized by the fact that between their pulsations we start to experience a temporal surplus (gap) that becomes dominant for IOI values larger than 1000ms *(Fraisse, 1964)*.

All these said, in order to memorize tempo 04 (A) in ex. II it would suffice to experience „the first isochronous tempo between whose pulsations we do not experience any temporal gap". A way to do that is to start from a slow isochronous tempo (e.g. IOI = 1400ms) and then come closer and closer to this perceptual threshold.

tempo 05 – (E) = IOI 840ms
As isochronous tempi have bigger and bigger values than those specific to the indifference interval (600-800ms, cf. *Fraisse, 1964)*, it becomes for us harder to define them experientially. Discrete time perception phenomena rarefy as we approach the limit of subjective rhythmization (IOI = 1500-2000ms cf. *Epstein 1995 et all.)*. Even if we consider this limit to be represented by the smaller value (i.e. 1500ms), it is hard to reproduce a corresponding isochronous tempo by committing ourselves „to line up pulsations in such a way that we would feel that a JND-type slowdown would transform a melody into «isolated sounds» *(Epstein 1995)"*, since theoretically there are still 500ms for this phenomenon to become perceptually apparent (i.e. after 2000ms). According to Fraisse *(1982)*, synchronization itself becomes a problem for IOI values grater than 800ms. For musicians, that means one thing: the necessity to elogize divisions in order to maintain a constant tempo and for synchronization – after all, slow tempi constituted one of the reasons why conductors were invented.
As a consequence, in order to memorize isochronous tempi belonging to the IOI = 800-1500ms area, it seems that the most rational thing to do is to acknowledge and assimilate the corresponding twice-as-fast tempi (or even thrice as fast for tempi belonging to the IOI = 1500-2000ms area).

Assuming that all these assertions are accurate, it means that tempo 05 (E) in ex. II should be memorized as the augmentation of IOI 420ms (i.e. 840ms ÷ 2). We can test experientially this IOI value by trying to see which is „the fastest isochronous tempo whose consecutive pulsations we can *not* elogize in thesis-arsis, arsis-thesis or compound (e.g. thesis-arsis-arsis etc.) groups". If that sounds Chinese, let us say that we are chasing „the fastest theoretical tempo of 1/x (e.g. 1/1, 1/2, 1/4) that we could experience". Feilgenhauer *(1912)* reached to the conclusion that the interval between two consecutive stimuli should be 200 to 400ms apart for subjects to have enough time to transfer their attention from one stimulus to the other *(cf. Fraisse, 1964)*. Mager *(Mager, 1925)* has established that the optimal rate of attention shift lies around 600ms. In brief, we have a minimum value of 200-400ms and an optimal one (i.e. 600ms) for attention shift rate in the case of two consecutive stimuli. In the case of the 200ms value, although perfectly valid, we can only operate with precisely *two* stimuli. However, if we want to experience longer rows of attention shifts, from one stimulus to the next, in the fastest cadence psychophysically possible, we shall find out that the IOI ≈ 400ms is the first sustainable rate. A series of personal experiments (of no proven scientific value, that is) have reached to a 420-430ms IOI value as the maximum rate of *sustainable* voluntary shift of attention. One of these experiments starts up from the image of any zig-zag:

ex. IV



In order not to imply in the experiment ocular saccades, we shall imagine mentally any similar zig-zag trying then to pass from one point to another (A, B, C, D, E, F, G, H etc.) is such a way that consecutive stops do not create, from a temporal point of view, subjective thesis-arsis relationships (nor binary neither compound – cf. supra) as we should perceive any stop as experientially equal to any other stop. Moreover, we shall make sure that each stop implies a thorough change of the object of consciousness (i.e. a complete transfer of attention). Upon these conditions, the next step is to find out (and measure), from a psychophysical point of view, which would be the maximum rate of passing from one point in the zig-zag to another. The result should indicate an IOI value situated around 420-430ms, which corresponds well to the IOI ÷ 2 value of tempo 5 (E) in ex. 2. The absolute memory (i.e. skipping the experiment just described, for that implies *relational* memory) for this isochronous tempo can be achieved by practice whereas memorizing tempo 5 (E) itself presupposes a bit of arithmetic and a minimal rhythmic feeling.

XX – A DEBATE
Acknowledging the specificities of each category of isochronous tempi within the temporal scope can be achieved in various ways. In the five cases chosen for illustration in the preceding Section (tempi 1-C, 2-B, 3-D, 4-A and 5-E in ex. II) I have chosen a variety of such methods – yet these are not the only possible. Not by the long shot. A professional

knowledge of isochronous tempi supposes a much wider morphological vocabulary in comparison to what was merely sketched out in the preceding Section. It is only thus that we shall be able to recognize any isochronous tempo upon hearing it and place it with precision on the scale of the musically workable temporal scope.

One of the problems of today musical time theory is that even musicians who are well introduced into the phenomenology of temporal perception have no representation of, say, these isochronous tempi, as they do not benefit from a corresponding semiography. Upon listening to a Bach chorale (see ex. I), musicians can pick up a pencil and notate what they hear: pitches, chords and durations – whereas listening to a MIDI file reproducing the 18 durations in ex. II they would probably describe every present isochronous tempo (like in the preceding Section, or even better), but asked to notate this music in a relevant-for-human-perception manner, they will most probably halt the pencil in midair.
Things are this way for at least two reasons. On the one hand, the main preoccupation of musicologists implied in the study of musical time cognition and perception was the better understanding of the *metro-rhythmical* system. Thus, the idea of creating a mental and/or graphical representation system for musical time, based *integrally* on temporal perception phenomena was not a noticeable presence amongst the studies dedicated to this topic. On the other hand, cognitive musicology is more about modeling and experiments whereas music theory is not, otherwise even Harmony treatises would have contained chapters starting with sentences such as „100 subjects were asked, in the frame of an experiment, to…".
In brief, musical time (understood in terms of human perception) still struggles to transform itself from object of scientific study into a fully fledged language and this struggle seems to postpone its end indefinitely.

XI – THE PERCEPTUAL NOTATION

More than ten years ago *(Pogorilowski, 1994)* I had proposed to the musical community such a notation system for discrete musical time – a semiography to appeal not to our rhythmic feeling (i.e. duration relationships between pulsations), but directly to human temporal perception mechanisms: i.e. the perceptual (or zeuxilogic) notation. It is not here the place to present it in detail but we can imagine graphically the first 17 pulsations in ex. II by resorting to the descriptions made in Section IX:

tempo 01-C (IOI 187ms)
Since in Section IX we have described this tempo as being defined by the minimum duration of an acton, we may shorthand it as „MAT" *(minimum acton tempo)*.

tempo 02-B (IOI 280ms)
Since we have defined it in Section IX as the triple of the fastest isochronous tempo in which we still can organize pulsations subjectively in groups of three, we may shorthand it as „FCB" *(fastest compound beat)*.

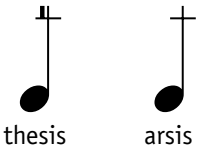
tempo 03-D (IOI 560ms)
Since we have defined it in Section IX as a IOI = 550ms tempo that we have memorized as such (as the third amongst a series of resonance-specific tempi), we may shorthand it as „3rdRST" *(third resonance-specific tempo)*.

tempo 04-A (IOI 700ms)
Since we have defined it in Section IX as the first tempo in which we do not perceive a temporal gap, we may shorthand it as „1stNGT" *(first non-gap tempo)*.

tempo 05-E (IOI 840ms)
Since we have defined it in Section IX starting from a twice as fast tempo, we may shorthand it as „MRSASx2" *(maximum rate of sustainable attention shift x 2)*.

Of course all these shorthands were invented ad-hoc, to fit the descriptions made in Section IX. Zeuxilogic semiography is meant to be an open-source kind of system and, until musicians convene at least over the number of isochronous tempi that we should discriminate (see Section VII), there won't be any standard perceptual notation.
Before writing down the pulsations in ex. II, I must mention that perceptual notation, not being metrical (i.e. it does not distribute thesis and arsis values implicitly), uses different (explicit) symbols for accents and non-accents.

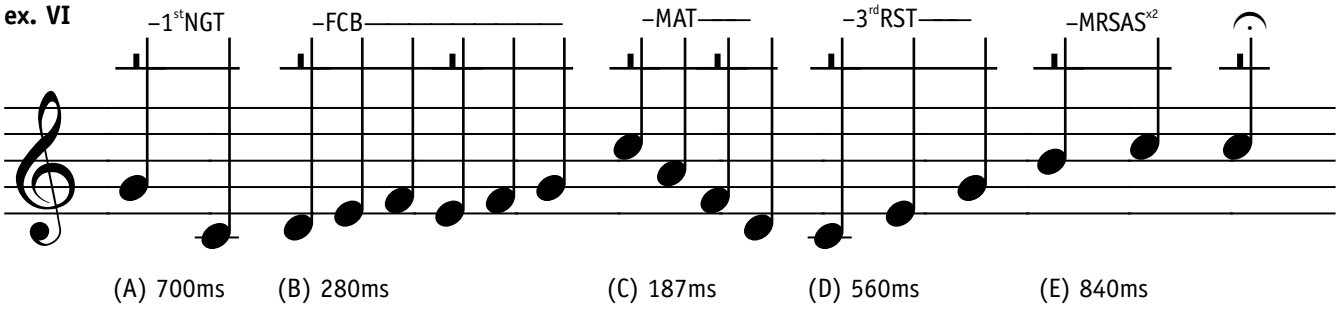
ex. V



All these said, here is how we may jot down in perceptual notation the pulsations of ex. II (see ex. VI).

In principle, a musician who masters well the whole bunch of temporal perception phenomena would need no shorthand marks, but only the IOI values expressed in milliseconds

ex. VI



(see the bottom line in ex. VI) that he/she would immediately relate to the corresponding perception phenomena. In so doing, he/she would rely on an aperceptual background well consolidated by a highly educated temporal hearing, thousands of hours of practice and specialized scholarship. Yet, such a timeologist-musician does not represent a standard today.

XII – A FEW SHORT CONCLUSIONS

Now we may perform the musical passage in ex. II written by our imaginary composer from a wholly perceptual perspective. Again, perhaps this is not precisely what the composer wanted from us but at least we did what we could to render a series of durations and isochronous tempi, from several perspectives.

Therefore, „the moment two isochronous tempi follow each other…" (see the beginning of Section I), there also is a perceptual perspective to define this passage, not only a durational one. Ex. VI presents four such successions. The five corresponding isochronous tempi are but a few, chosen for a mere illustration, amongst those that humans can discriminate within the musically workable temporal scope. Knowing them all theoretically and then memorizing them will provide us with the ability to recognize and categorize any isochronous tempo upon hearing it – the same way musicians are able to recognize and categorize, on the spot, intervals, chords or metro-rhythmical structures that are common to the current musical practice. More so, we have seen how, by means of zeuxilogic (perceptual) notation we may now notate these isochronous tempi from a wholly perceptual perspective.

The notation of isochronous tempi represents but a part of zeuxilogic semiography, which also encompasses graphical representations for temporal windows (i.e. units of perceptual present), accentuation categories, equally-lasting pulsations that cannot create isochronous tempi (e.g. crushing notes) or non-isochronous pulsatory structures (e.g. those similar to the dotted rhythms or the swing from the metro-rhythmical system) etc. As it is meant to be an open-source type of system, it is only the limits of imagination that may avert perceptual notation from acquiring new features.

The secondary message of this study (already heralded in Section X) is that the perceptual perspective over musical time does not as yet benefit from the attributes of a proper musical language. I wonder what would have happened if the classification of isochronous tempi, from a wholly perceptual perspective, took place before psychophysics, experimental psychology, millisecond measuring devices, computer or even music academies have been invented. It is probable that today we would have had in our hands an intuitive system for representing musical time perceptually that would have been a congregation of debatable terms (of which classical harmony is not spared at all, for that matter) but which – to the extent that system would have had produced a series of musical masterpieces – might have been accepted by the musical community of today as a valid and viable heritage-language. Whenever I finish reading a cognitive musicology study dedicated to musical time I stop and wonder whether, in this field, technology and science are a blessing or a curse. It will be only the largely accepted transformation of temporal perception and cognition from an object of scientific study into a proper musical language that will give an answer to this dilemma.

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