

# PREFERRED TEMPO RECONSIDERED

*Dirk Moelants*

IPEM-Dept. of Musicology  
Ghent University, Belgium

## ABSTRACT

In the current literature preferred tempo is usually located around 100 bpm (600 ms) (Fraisse, 1982). We will give a review of more recent experimental evidence and present a series of experiments and analyses of existing data that show that preferred tempo is located at a significantly faster speed. It will be shown that it is located somewhere between 120 and 130 bpm, so 500 ms (120 bpm) is more realistic as characteristic period for preferred tempo. The existence of this optimum in tempo perception and production will be used to support the resonance theory of tempo perception (Van Noorden & Moelants, 1999), according to which tempo perception and production is closely related to natural movement, with humans functioning as a kind of resonating systems with a natural frequency.

## 1. INTRODUCTION

Tempo can be defined as the rate of something regularly repeating. In music perception 'tempo' is used for the speed of the beat (or pulse) -i.e. the dominant (apparent) periodicity underlying the music-, and with repetitive movements associated with it (dancing, finger tapping,...).

The perception and production of these periodic movements has lower and upper borders. Perceptually, sounds fuse together to form one continuum when the repetition rate is too high. When the distance between the individual pulses gets too large, they appear as isolated. It seems that we should be able to keep at least two successive beats in our working memory to perceive the succession and its regularity. We find these limitations back in movement patterns: we can not perform infinitely fast repetitive movements, certainly not in a controlled way, and when we have to move extremely slowly this is not longer perceived as a continuous movement, but as a series of independent movements.

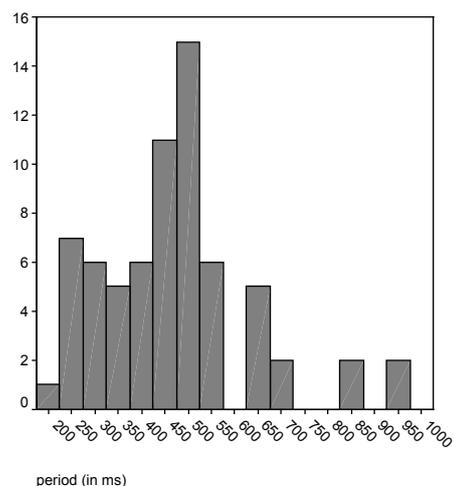
Combining evidence from different fields, the borders of the 'existence region' of tempo were fixed between 40 and 300 bpm (periods between 200 and 1500 ms) (Van Noorden & Moelants, 1999). However these numbers are approximate and should be interpreted as labels for a small 'tempo zone'. Determining the borders exactly is difficult, mainly because the transition is not abrupt, but gradual: tempi near the edges of the existence region are still not so easy to perceive or to perform. This implies that somewhere in the middle there must be a point or a zone where tempo perception is optimal: 'preferred tempo'.

## 2. DATA

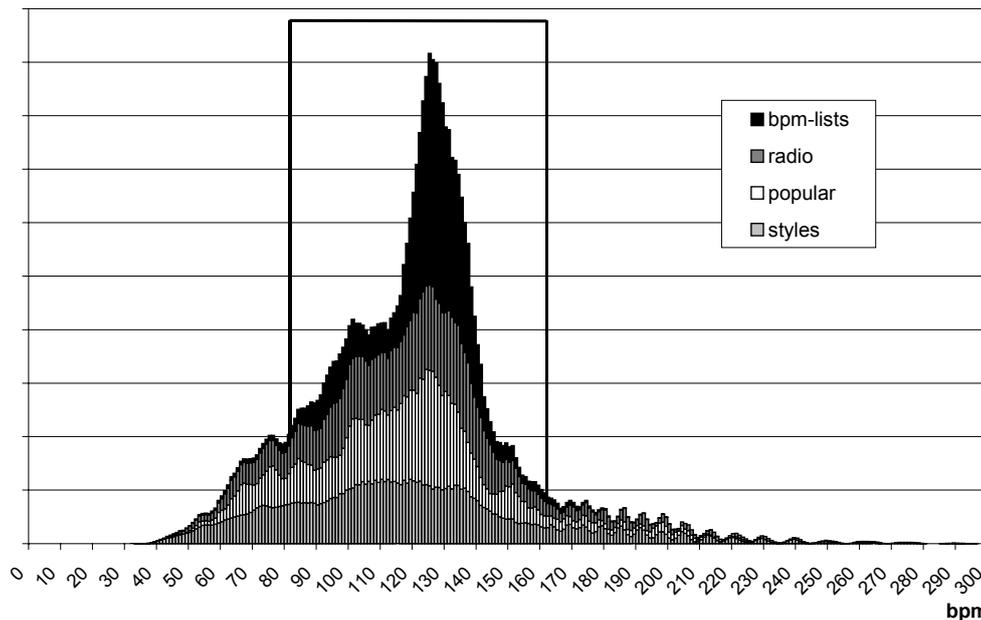
### 2.1. Preferred Tempo of Repeated Movements

Up to now the main source used when referring to preferred tempo or related concepts like spontaneous, optimal or natural tempo is the work of Paul Fraisse (1982). He collected data from several sources and concluded that there was a large variability, but that 600 ms was to be taken as the most characteristic period.

In recent years only a few researchers investigated the phenomenon of preferred tempo explicitly, mostly within a broader experimental framework. Collyer, Broadbent & Church (1994) made their subjects tap at a 'comfortable rate' several times. The most remarkable result of their experiment was a strong tendency to move to faster tempi after a few trials. When we look at the initial average responses, we see periods between 460 and 490 ms for the first six trials. A period of 490 ms was also found by Kay, Kelso, Saltzman & Schöner (1987) as average preferred tapping rate when subjects tapped with one hand. For more complex tasks -like alternate tapping with both hands- averages were slower. Additionally we asked 34 musically trained subjects to tap 'at a comfortable rate' before and after an experiment on tempo synchronization (Moelants, 2002). On the total number of 68, the average period was 467.3 ms, but again the variance was large, answers ranging from 191 to 953 ms. The distribution is shown in figure 1, the peak between 450 and 500 ms is clearly visible.



**Figure 1:** Distribution of the periods of 'spontaneous tempo' as found by Moelants (2002).



**Figure 2:** Distribution of the tempi as perceived in four sets of musical pieces. The black frame indicates the 'preferred octave'.

Thus, in three independent laboratory experiments with different experimental conditions, a preference for periods just below 500 ms was found. If this indeed corresponds to a spontaneous, natural type of movement, we expect to find similar periods in some typical repeated motor actions. The most obvious candidate is the natural walking speed. The mean period of normal walking was set at 513 ms (117 bpm) for adult males (Murray, Drought & Kory, 1964). But also here large interindividual differences occur, depending e.g. on age and gender, with averages ranging between 400 and 740 ms (Whittle, 1996). This is fairly close to the distribution of preferred tempi in finger-tapping experiments, although the averages are slightly higher. A second type of spontaneous repetitive act is found in applause. It was shown (Néda, Ravasz, Brechet, Vicsek & Barabasi, 2000) that two types of applause exist, each with their own characteristic frequency: fast spontaneous applause and slower, rhythmically synchronized applause. Between both we find more or less a doubling in frequency, from 253 tot 493 ms average. Secondary peaks around 250 ms were also found in two of the tapping experiments (Collyer, Broadbent & Church, 1994; Moelants, 2002). It seems to correspond to a different type of movement, a fast but still comfortable rate. The 'harmonic' relation with the main period might indicate that both have a similar origin.

## 2.2. Distribution of Tempi in Music

If there is a connection between our natural preference for tempi around 120 bpm in spontaneous movements and our perception of tempo in music, we expect to find a relatively large number of tempi around this preferred rate when looking at the distribution of tempi as perceived in music. Since tempi indicated in the score do not always coincide with what people

perceive as the beat, we have to collect perceptual data about tempo perception in music. First we collected existing perceptual data, using 'bpm-lists' available on the internet. These lists contain tempi for dance music and are used by DJs to be able to make fluent transitions between the records they play. The use of 'bpm-lists' has three important advantages: 1. The data are necessarily perceptual since they are collected directly from the sound and must represent the tempo perceived by the dancers; 2. These lists contain music from different styles, but concentrate on dance music, which gives us a clear link between natural movement and tempo perception; 3. The amount of data is enormous (74042 pieces), which allows conclusions with a high statistical relevance.

In addition to this we collected tempi experimentally, letting subjects tap along with specific selections of music. Three types of material were used: 1. 'Random' music heard on the radio, changing program after every 40 taps; 2. A selection of hits from the period 1960-90 as collected in a CD-series giving a historical overview of popular music; and 3. Selections of music taken from specific, but divergent styles, ranging from renaissance polyphony to modern jazz. These three collections of tempo should give a complete view on the distribution of perceived tempo as it is found in western music. More details about the bpm-lists and the experimental procedures are given in Moelants (2002). An overview of the central tendencies in the four sets of data is given in table 1.

Again all the results are grouped around the 500 ms period (115-127 bpm or 472.4-521.7 ms). The most remarkable result is the similarity of the preferred 'tempo octaves' (containing the most possible entries within one 'octave', or doubling of the tempo). For each of the four data sets, the 'octave' 81-162 bpm (370-740 ms) is found as optimum. Moreover this zone nearly coincides with the range of average walking speeds (400-740 ms) as discussed in the previous chapter.

series	mean	median	mode	'octave'
radio	116.4	117.9	123	81-162 (81.0%)
popular	115.5	116.8	124	81-162 (82.1%)
styles	120.2	117.0	118	81-162 (68.8%)
bpm-lists	124.9	127	127	81-162 (96.2%)

**Table 1:** central tendencies of the tempi as perceived in 4 sets of musical pieces.

Despite the similarity of the averages, there is an important difference between the different categories, indicated in the percentage of responses within the preferred octave. For the music from different styles 'only' about two thirds of the responses fall within the preferred octave, indicating a relatively large amount of 'extreme' tempi. This while for the dance music in the bpm-lists almost all entries fall within the preferred tempo octave. Another view on the distribution is given in figure 2, in which the results of the four data sets are superposed. Here we see a very clear peak around 125 bpm (480 ms), slightly faster than the average values given above. This is caused by a relative 'overrepresentation' of slower tempi, which makes the distribution not strictly symmetric.

These data, representing tempi as perceived in a broad range of musical styles, but focussing on popular music and dance music, corroborates the results of the experiments on repeated motor movements reviewed in the first chapter. There clearly is an agreement between the tempi we use in spontaneous movements like walking, clapping and finger tapping, and the tempi we perceive in music. Within the preferred octave there is still a prominent peak around the preferred tempo. This indicates that there is not only a tendency for the listeners to interpret the music in a tempo within a certain zone, but also that tempi around preferred tempo are more often performed than tempi near the edges of the preferred octave. Thus both performers/composers and listeners seem to have a preference for tempi slightly faster than 120 ms.

### 3. RESONANCE MODEL FOR TEMPO

In Van Noorden & Moelants (1999), we presented a first attempt to model tempo perception based on physical resonance. We could not exactly fix the natural frequency, although the results already pointed to the area around 2 Hz (120 bpm, 500 ms). Here we will briefly review the principles of the model and then present the resonance curve that follows the characteristics discussed above.

Objects have a natural frequency, the tempo with which they move when they are hit while fixed at one end. This frequency can be apparent in the movement of the object or in the pitch it produces. Another factor, the 'damping', determines the speed with which it returns to rest. Typically objects with a low

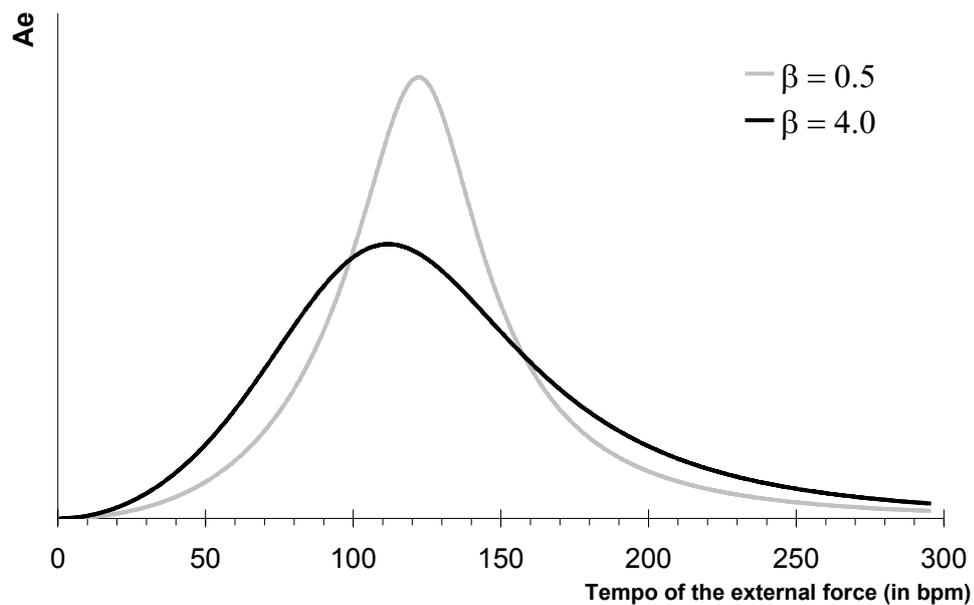
damping start moving with an amplitude corresponding to the power of the external force and then slowly return to rest, with a diminishing sinusoidal movement. The higher the damping, the faster the object returns to its resting position. When we hit the object periodically and the period of the external force corresponds to its natural frequency, the movement of the object will grow far beyond the amplitude corresponding to the power of the external force. In extreme cases the movement can even force the object to 'explode'. When the period of the external force lies close to the natural frequency we still have some of this 'resonance' effect. However, when the period is much longer, the maximum movement will not grow stronger than the input power. When the period gets shorter the movement will even get smaller and eventually stop because the natural movement is constantly disturbed by the external power. In a normal physical system the formula describing the amplitude ( $A$ ) of the movement of the oscillating object with natural frequency  $f_0$  and damping  $\beta$  in relation to the frequency of the external force is given by:

$$A = \frac{1}{\sqrt{(f_0^2 - f_{ext}^2)^2 + \beta f_{ext}^2}}$$

Now we can transfer this idea to a person listening to music. In that case we have to consider the person as an object with a natural frequency and the beat of the music as the external force. If the person finds in the music a period close to his natural tempo, he will have the tendency to start moving at this tempo. Moving at tempi a bit further from the natural frequency is still possible, but less easy. Very fast tempi can not be followed any more since our mechanics do not allow very high repetition rates for movement. Very slow tempi are mechanically possible, but here a very different mechanism, memory, interacts with the physical model. Subtracting from the normal resonance curve a 'critically damped' curve with the same natural frequency can solve this problem. 'Critically damped' means that  $\beta$  is that large that the system gets too 'stiff' to resonate, even when stimulated by an external force periodically moving at the natural frequency of the object, it will not gain extra power. By only keeping the difference between a normal and a critically damped curve, we only preserve the additional movement due to the resonance phenomenon, independent of the power of the external force. This adapted version of the resonance curve can be obtained by the following formula:

$$A_e = \frac{1}{\sqrt{(f_0^2 - f_{ext}^2)^2 + \beta f_{ext}^2}} - \frac{1}{\sqrt{f_0^4 + f_{ext}^4}}$$

In figure 3, two examples of these 'effective' resonance curves are given both with  $f_0 = 2.08$  (480 ms, 125 bpm), but one with relatively high damping ( $\beta = 4$ ) and one with low damping ( $\beta = 0.5$ ). The difference is clear: with higher damping the distribution gets broader and the peak becomes less prominent and slightly moves to a slower tempo than the actual resonance frequency.



**Figure 3:** Examples of 'effective' resonance curves with the same natural frequency but a different damping.

#### 4. CONCLUSIONS AND IMPLICATIONS

The central issue in this paper was a reconsideration of the location of natural or preferred tempo. Until now it was generally located around 600 ms (100 bpm), but we showed that a period slightly below 500 ms is probably more realistic. As characteristic period we chose 480 ms (125 bpm), but since this is just an average 500 ms could be used for convenience. This tempo was found in both the preferred rate of repeated motor actions and in the peak in the distribution of tempi as perceived in various sets of musical data. This tight link between natural movement and tempo perception was already present in the resonance modal of tempo perception as developed by Van Noorden & Moelants (1999), in which human tempo perception is modeled starting from the phenomenon of physical resonance. In this paper this model was given a more or less fixed natural frequency, the other free parameter, the damping, seems much harder to fix. It could be related to the mood or the 'stiffness' of a subject, e.g. changing from a high damping when attentively listening to classical music to a low damping while dancing at parties. This change corresponds to differences found between the distribution of tempi in different data sets.

Further research is necessary to find the nature of the natural frequency. It could be related to existing theories in which tempo perception is modeled using oscillators, and if it is indeed a characteristic of our body it must be possible to find it back in physiological research. In any case the use of the proposed curve could be used as an element in models for beat tracking and tempo recognition providing a realistic account of tempo preference.

#### 5. REFERENCES

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