Understanding Supersaturation:
A Musical Phenomenon Affecting Perceived Time

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Abstract
This study emanated from the composer’s real-life experience of extreme time dilation (time slowing down) while mixing 128 tracks of a dense musical composition (Andarta). A series of psychoacoustic experiments were built around an array of sonal stimuli and indicated evidence that an extremely dense state ("Supersaturation"), at the borderline between multi-layered texture and timbre, contributes to the slowing up of perceived time. The progression from less dense to highly dense texture was examined with respect to selected musical parameters and three basic "natural schemata": 1) definability; 2) range of occurrences (related to the normative state; and 3) directionality. The first experiment tracked musicians and non-musicians’ “re-performing” of aural stimuli on buttons and a data gathering apparatus. Other experiments utilized non-quantitative comparisons of the same paired musical patterns, through questionnaires. The striking results have led to preliminary conclusions and use principles for understanding time dilation and music.

1. Introduction
The investigation of time has occupied scientists and philosophers throughout the ages. Today, the on-going challenge of understanding the sense of subjective time, in relation to physical time, remains paramount in many fields of inquiry (such as neural networks, psychology, psycholinguistics, and dream research). For musicians, musicologists and composers, this understanding has begun to provide vital clues as to how pieces of music “work”, and how those pieces may effect the minds of listeners. Biological and psychoacoustic determiners of how time is perceived, seem to span diverse cultures and peoples. How various cultures and peoples choose to organize common musical material is, however, extremely varied—and determines what is known as musical “style” and aesthetic sense. Indeed, one of the key determiners of musical style is the sense of time. Thus, each culture’s own aesthetic ideal relates to how one senses the passing of time and how common musical material is organized to mold this time sense.

We may speak of two interrelated aspects of the perception of time in music: 1) time as an axis on which is organized the musical elements creating “qualitative flow” with types of directionality and complexity (such as flowing/static, clear/blurred, complex/simple; we also remember that composers speak of musical “space” and “stopping time” (Cohen, 1994) and 2) the sense of subjective time (quantitative), perceived by the listener, in relation to physical time. (Cohen, 2001). The following experiment in the perception of time seeks to explore aspects of the second aspect, through empirical means. This research was inspired by real-life listening and composing experiences in which dense sound environments seemed to slow time down to the point of nearly stopping.

2. Background
This study builds on the work of many researchers; here, are a few significant ones are named. Early storage models (Ornstein, R., 1969) showed that complexity of auditory stimuli and increased number of stimuli to the brain, led to the lengthening of perceived time. This was qualified by effects of memory (Block, R., 1978, 1985 and others). More recent experiments demonstrated the effects of cadence, where an unexpected cadence shortens the perception of time (Boltz, 1992), a cadence after an expected cadences lengthens the perception of time (Boltz, 1989). Orderly events contribute to an accurate assessment of time (Boltz, 1994). Incoherent events in various respects lengthen the time (Jones and Boltz, 1989) and non-concurrence of events (Zakay, D., 1989) also lengthens the perception of time. Complexity of prospective time (at the moment, immediate) has a shortening effect, while complexity of retrospective time (from the past, larger structure) has a lengthening effect (Zakay, D., 1989). The effect of the density of events depends on prospective time, retrospective time and the type of events and, attention to time lengthens it, i.e. if you wait for a light, it seems very long (Zakay, D., 1998).

However, previous research has not dealt with extreme departures from the normative state, often referred to as the Inverted U function (Hargreaves, 1986); in music, this can be
found in extremes such as. very slow vs. very fast; very soft vs. very loud; few changes vs. many changes; very thin vs. very dense). While examining properties of highly dense textures, this research sought to find relationships to these kinds of extreme states and their effect on the perception of time.

3. The Experiment

The goal of this experiment was to uncover what contributes to the feeling of subjective time in relationship to physical time, with respect to the principles of the musical rules and the different inherent parameters. Though the topic has recently engaged more researchers, there is still no clear picture of the different operative factors affecting time, especially in relationship to music. Here, I choose to focus on three principles with different musical parameters which seem to have great importance to musical organization. I certainly do not claim to cover all the ground that needs to be covered. Toward this goal, I have conducted this experimental work.

3.1 The Subjects

Nineteen subjects between the ages of 18-30, mean age, 25, (compared to 48 subjects in Experiment No. 1) participated in this study. Within the group, 5 were chosen as “experts”, with respect to certain criteria. All in all, the 19 subjects were “musicians” (who were actively enrolled in a music conservatory and/or who declared at least 2 years of explicit musical training and/or proficiency in one or more musical instruments). Each participant was paid $10 for his or her participation.

3.2 The Examined Patterns

The examined patterns were presented individually in different durations of 6, 10 and 15 seconds. Some were excerpted from the Western musical repertoire (Ives, Ligeti, Horenstein) or Non-Western (Tibetan chant); others were harmonic patterns that appear in the Western musical repertoire (Mozart, Schubert, Debussy); and some were composed especially for this experiment. Each example (in each type) appeared in different states, with respect to the three principles (Degree of Definability, Range of Occurrences, and Degree of Directionality). All together, there were 38 different patterns used with different lengths. They all related to three principles:

- **Degrees of Definability**: a) Rhythm (drum playing); b) Beat (percussion playing); c) Combination of parameters (Charles Ives, Stephen Horenstein)
- **Range of Occurrences**: d) Speed (percussion playing); e) Register (Tibetan chant, Random piano playing); f) Simple melody (on piano, played in 3 registers)
- **Degrees of Directionality**: g) Simple melody in same register (piano playing); h) Harmonic patterns (derived from Mozart, Schubert, Debussy; piano playing)

Of special importance to the “supersaturated” texture was the extreme departure from the normative state (**Range of Occupurences**) and ways that the other principles might contribute to this in an accumulated fashion.

3.3 The Task

After listening to each of 54 patterns, the subject had to repeat the perceived time duration by pressing a button twice, at the beginning and end of the time interval. This was performed on a machine built especially for this experiment.

3.4 The Data Collection and Analysis

Data was analyzed by calculating the mean of all nineteen responses for each listened pattern. The difference of this average was compared to the original length.

Description of Testing Apparatus

**Hardware:**

A model D24/CTR digital input-output PCMCIA data acquisition card made by Measurement Computing (http://computerboards.com) was installed on a laptop computer (Compaq, Presario Model #1692, 450 mhz.). This data acquisition card has 24 electrical inputs and can determine the binary logic state (logic 1 or 0) of each input individually.

Note: In a digital logic system, a logic 1 corresponds to a voltage of 5 volts, and a logic 0 corresponds to 0 volts. Only 16 of the 24 available input terminals on the D24/CTR were used for this experiment. Sixteen 2-conductor cables were cut to lengths of about 5 meters. One of the conductors from each cable was connected to one of the 16 input terminals of the D24/CTR card; the other conductor from each cable was connected to a source of 5 volts provided by the card. The other end of each of the 16 cables was connected to a simple pushbutton switch. Pressing a given switch thus applied a voltage of 5 volts (logic 1) to that cable’s input terminal on the D24/CTR. Not pressing the switch resulted in the application of 0 volts to the input terminal, i.e., a logic 0.

**Software:**

The software module DAS-Wizard was installed on the laptop. This software creates a “macro” function in Microsoft Excel which interrogates the D24/CTR card on command and stores the binary logic values of each input terminal in spreadsheet cells. (Eight binary logic values are stored in one spreadsheet cell. In this case, two spreadsheet cells were used.). A custom macro program for Excel was written in Microsoft Visual Basic to read the binary status of the 16 input lines approximately once every 100 milliseconds. Because Visual Basic macro routines utilize the internal software clock of the laptop, and because the latter can vary slightly from machine to machine, the exact sampling interval was determined and fine-tuned by instructing the program to take 1000 samples and recording the required sampling time with a stopwatch. A software adjustment was used to calibrate the program to the laptop used for the tests. Multiple calibration runs were performed to

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ensure the accuracy of the timing interval. The resolution of the finished program was approximate 0.1 seconds.

The sampled input-port readings, indicating the pushed/not-pushed status of the 16 switches, were transferred to individual spreadsheet cells for post-test evaluation. The total duration of the sampling interval could be altered by the user by entering the desired number of seconds of sampling into one cell of the spreadsheet. After the entire sampling interval, the program determined the percent of the sampling interval that each of the 16 buttons was pressed, then calculated the total number of seconds that each button was pressed. These data were then transferred to a second page of the spreadsheet that could be saved to disc to produce a permanent record of the test.

3.5 The Assumptions

This study proposes that the perception of subjective time is dependent on and effected by a number of principles which may be present in various states of the different musical parameters (here we have focused on the following three principles):

1) The Degree of Definability* which may occur through the appearance of different characteristics (by the appearance of a single parameter-- the degree of its regularity; the laws of organization which govern its different units; by the degree of concurrence between different simultaneous events of different parameters;

The assumption: As the degree of definability is less, it will lengthen the duration of our time sense.

2) The Range of Occurrences ** in relationship to the normative range, in relationship to the different parameters.

The assumption: As the degree of departure from the norm is greater (over the boundary toward the “more” or toward the “less”), it will lengthen the duration of our time sense.

Example of deviations toward the “more”: very loud, fast, high, with many contrasts and changes; toward the “less”: very soft, slow, low, with few contrasts and changes.

3) Clarity/lack of clarity in Directionality of melodic units or harmonic patterns.

The assumption: The increase of uncertainty throughout the process (blurring of directionality) causes the lengthening of the duration of time.

* Here definability is not represented by exact quantitative size, but by general connotation in the musical world. For instance, rhythm, with concurrence between the event and the beat, is more defined than with syncopation—and even more, with rhythm without beat or irregularity. Or melody—with symmetry of its phrases, it is considered defined, and if asymmetrical, less defined; traditional melodic contour of gradual rise and fall is defined, where one with a great deal of abrupt zig-zag movement is considered less defined.

** Range of Occurrences is related to the inverted U function (Hargreaves, 1986), which can be related to many parameters, with deviation from the norm, one toward the “less” and the other toward the “more”.

3.6 The Parameters

The parameters that may appear in the three principles cited above are here listed:

1) From the parameter of Pitch are derived register, ambitus, curves, melodic rules, tonality and harmony (these contribute to all three Principles—1st, 2nd and 3rd).

2) From the parameter of Duration are derived beat, rhythm, meter, tempo (these relate to the 1st and 2nd Principles)

3) From the parameter of Loudness are derived 3 basic degrees of loudness, more or less, crescendo-diminuendo (this parameter relates to the 2nd Principle)

4) The parameter of Timbre is secondary, as a “help-tool”.

5) All of the above may appear alone or in different combinations of the above with concurrence (low with soft, slow and no changes).

4. The Results of the Experiment

Most of the results (70 %), of this experiment supported the hypothesis with respect to factors that influence the lengthening of perception of time. An additional (17%) of the results raised unexpected questions that, after discussion, shed new light on the hypothesis. (13 %) of the results were inconclusive. We divided the results into three groups:

1) Those with highly conclusive responses (including 8 types which appear in different states, including 33 patterns).
2) Those with interesting and unexpected responses (including two types which appear in different states, including 8patterns).
3) Those with less conclusive responses

In the interest of brevity, we will examine the conclusive results, and correlations with later experiments.

4.1 Highly Conclusive Responses

It is possible to interpret most of the results by two functions, according to the principles selected for the experiment and our assumptions: 1) linear ascending (/)---which relates to the 1st Principle, Degree of Definability or the 3rd Principle, Degree of Directionality-- or 2) U (Inverted U or U function)--which relates to the 2nd Principle, Range of Occurrences. Y Axis is the amount of lengthening and X axis, the states of the different parameters in the different principles. Here, as contrast to Experiment No. 1, results are presented by precise quantities. Each result is presented by a small table of numbers, which
represent the findings and a figure with Y Axis as a function of X Axis (like the figure below).

Different states of different parameters, in different principles

4.2 Data: Highly Conclusive Responses

The following are graphic representations of data, highly conclusive responses:

Result 1)

Figure of Table i: % of lengthening as function of Three Degrees of Speed (as represented by 1=2.1, 2=2.2 and 3=2.3)

Result 2)

Figure of Table ii: % of lengthening as function of Three Registers of Absolute Pitch (as represented by 1=5b.1, 2=5b.2 and 3=5b.3)

Result 3a)

Figure of table iii a: % of lengthening as function of Range of Occurrences (represented by 1=8.1, 2=8.2 and 3=8.3) (10 sec.)

Result 3b)

Figure of table iii b: % of lengthening as function of Range of Occurrences (represented by 1=8.1, 2=8.2 and 3=8.3) (6 sec.)
Rhythm, Degrees of Definability and Complexity (Drum Playing)
6 seconds

<table>
<thead>
<tr>
<th></th>
<th>defined</th>
<th>less defined</th>
<th>not defined</th>
</tr>
</thead>
<tbody>
<tr>
<td>% longer</td>
<td>29</td>
<td>35</td>
<td>26</td>
</tr>
</tbody>
</table>

Figure of table iv: % of lengthening as function of Rhythm, Definability and Complexity, (1=1.1, defined; 2=1.2, less defined; 3=1.3, not defined)

Three Degrees of Definability
Andarta, Horenstein (15 seconds)

<table>
<thead>
<tr>
<th></th>
<th>defined</th>
<th>less</th>
<th>not def.</th>
</tr>
</thead>
<tbody>
<tr>
<td>% longer</td>
<td>7.8</td>
<td>8.6</td>
<td>9.3</td>
</tr>
</tbody>
</table>

Figure v: % of lengthening as function of Rhythm, Definability and Complexity Three Degrees of Definability (as represented by 1=6b.1, defined; 2=6b.2, less defined; 3=6b.3, not defined)

Three Degrees of Ambitus
Vocal/Orchestral Playing, Ligeti (10 seconds)

<table>
<thead>
<tr>
<th></th>
<th>narrow</th>
<th>normative</th>
<th>widest</th>
</tr>
</thead>
<tbody>
<tr>
<td>% longer</td>
<td>18</td>
<td>14</td>
<td>9</td>
</tr>
</tbody>
</table>

Figure of table vi: % of lengthening as function of Three Degrees of Ambitus

Three Degrees of Absolute Pitch
(Tibetan Chant) 10 seconds

<table>
<thead>
<tr>
<th></th>
<th>low</th>
<th>medium</th>
<th>high</th>
</tr>
</thead>
<tbody>
<tr>
<td>% longer</td>
<td>15</td>
<td>18</td>
<td>21</td>
</tr>
</tbody>
</table>

Figure of table xii a: % of lengthening as function of Three Degrees of Absolute Pitch (10sec.)

Three Degrees of Absolute Pitch
(Tibetan Chant) 6 Seconds

<table>
<thead>
<tr>
<th></th>
<th>low</th>
<th>medium</th>
<th>high</th>
</tr>
</thead>
<tbody>
<tr>
<td>% longer</td>
<td>18</td>
<td>21</td>
<td>9</td>
</tr>
</tbody>
</table>

Figure of table xii c: % of lengthening as function of Three Degrees of Absolute Pitch (6 sec.)
Different Degrees of Directionality in Harmonic Patterns

<table>
<thead>
<tr>
<th>% longer</th>
<th>A1</th>
<th>A2</th>
<th>B</th>
<th>C</th>
<th>D1</th>
<th>D2</th>
<th>D2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>7</td>
<td>8</td>
<td>11</td>
</tr>
</tbody>
</table>

Figure of table xxiii: % of lengthening as function of Different Degrees of Harmony

The above example types (A, B, C, D) include:

A. (Tonal simple harmonic patterns with “strong steps” (according to Schoenberg, 1954), and archetypical harmonic degrees (I, IV, V, I), very directional.

B. Tonal patterns with “weak steps”, and not with archetypical harmonic degrees, not “flowing”.

C. The chords as timbre without harmonic function (from Prelude for piano, in the 2nd Volume, by Claude Debussy).

D. Harmonic patterns, with enharmonic changes, most unidirectional (from the Requiem, by W.A. Mozart, with one enharmonic change; from the lied Guidepost (Wintereisen) by F. Schubert, with chain of enharmonic changes.

It is possible to examine the results of the experiment and see which singular examples effect the time sense to a greater degree. They are (in the order of highest percentage of increased duration from the example)

a) Rhythm, degrees of speed (slow, attack density 9, short duration, 6 sec.), 39%
b) Rhythm, degrees of definability and complexity (somewhat undefined), 30%
c) Rhythm, degrees of speed (fast, attack density 72, longer duration, 10 sec), 26%
d) Rhythm, degrees of speed (fast, duration 10 sec.), 26%
e) Exaggerated degrees of departure from the “norm” (high, fast, loud, jagged), 24%
f) Three degrees of absolute pitch (high, rich in overtones), 21%

In the realm of harmonic patterns, non-directional patterns were perceived as much as 73% longer than directional ones!

In the realm of regularity-irregularity of accented patterns (15 seconds), maximum of equality of events (with equality and non-equality of accents) were perceived as 70% longer over an extended period of time.

We conclude the following from this experiment that most powerful “tools” for “stretching” the time sense may include the following (or their combination):

1) Greater rhythmic complexity
2) Greater density of attacks
3) Greater sparseness of attacks
4) Greater deviation from the norm (especially deviation toward the “more”)
5) Greater blurring of definability
6) Extremes (particularly high) degrees of absolute pitch (ambitus)
7) Less harmonic directionality
8) Maximum of equality of events (with equality and non-equality of accents) over an extended period

5. Other Experiments and Correlations

5.1 Description of the Second Experiment

A second experiment was performed utilizing questionnaires. 48 subjects between the ages of 18-30 (mean age, 25) participated in the experiment. They were divided into two groups: 25 “musicians” (who had declared at least 2 years of explicit musical training, defined as enrollment in a music conservatory and/or proficiency in one or more instruments) and 23 “non-musicians”. Each participant was paid $10 for his or her participation. Examined patterns were paired both in identical lengths (10, 15 or 19 seconds) and in pairs with slightly different lengths (variance of .5 seconds). Listeners received a questionnaire, asked to fill out their names, age and amount of learning. They were then told that they were about to hear a series of pairs of musical fragments. After listening to each pair, they were to choose one of the following options: a>b (a “sounds longer” than b), b>a (b “sounds longer” than a), a=b (a “sounds the same” as b), and “not sure”. Between each example pair, there was a brief pause of 3 seconds. At the end of the experiment, they had the choice to write their remarks concerning their role (i.e., if it was easy or difficult) and other general responses.

5.2 The Data Analysis

Data was analyzed with respect to the kinds of comparison of the patterns within the pairs, and with respect to the various variables of pair members. In these comparisons, data was analyzed within each example category and sub-category, also with respect to durations of the patterns within the pairs (whether they were of identical length or of slightly different lengths). In pairs of unequal length, significance was also given to the response “a=b”, as this response indicated a clear tendency toward perceiving one of the pair members shorter or longer than the other. In these cases, the term “non-significant” (used by the statistician to denote an even distribution of responses (through the four possible responses: a>b, b>a, a=b, and “not sure”) took on a different meaning, as there was now a “significance” through these kinds of responses to pairs of unequal length.
5.2 Results and Correlations with First Experiment

In the second experiment, most of the results, (70%) supported the hypothesis with respect to factors that influence the lengthening of perception of time. An additional fifteen percent (15%) of the results raised unexpected questions that, after discussion, shed new light on the hypothesis. Fifteen percent (15%) of the results were inconclusive.

Some of those stronger results (approximate relationships, not exact quantification) are summarized below:

**Conclusion 1): As it is faster, it is perceived as longer:**

<table>
<thead>
<tr>
<th>Moderate</th>
<th>Faster</th>
<th>Fastest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pattern # 2.1</td>
<td>&lt; 2.2</td>
<td>&lt; 2.3</td>
</tr>
</tbody>
</table>

Perceived longer, despite 2.3 was shorter

**Conclusion 2): As it is less defined, it is perceived as longer**

<table>
<thead>
<tr>
<th>Defined</th>
<th>Less Defined</th>
<th>Not Defined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pattern # 1.1</td>
<td>&lt; 1.2</td>
<td>&lt; 1.3</td>
</tr>
</tbody>
</table>

Perceived longer, despite 1.3 was shorter

**Conclusion 3): As it moves toward “deviation to the more” it is perceived as much longer than the normative, and somewhat longer than the “deviation to the less”, especially with extreme, exaggerated and contrasting degrees.**

<table>
<thead>
<tr>
<th>Deviation to the less</th>
<th>Normative</th>
<th>Deviation to the more</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1</td>
<td>8.2</td>
<td>&lt;&lt; 8.3</td>
</tr>
</tbody>
</table>

Somewhat perceived as longer       Perceived as longer

**Conclusion 4): As it is less harmonically directional, it is perceived as longer. As it is more enharmonically-chained and without harmonic direction, it is perceived as longest:**

<table>
<thead>
<tr>
<th>Tonal chords as timbre</th>
<th>enharmonic (one change, several changes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1, A2, B</td>
<td>&lt; C</td>
</tr>
</tbody>
</table>

**Perceived as longer** **Perceived as longest**

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**One important final observation:** In BOTH experiments, there were NO significant differences in the responses of musicians and non-musicians—which leads us to believe that musical training does not seem to impact on such time perception.

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6. Derived Principles of Time Perception

1) Extremes of speed (and greater event density) tend to lengthen perception of time.

2) Extreme degrees of register (very low and very high) tend to lengthen perception of time.

3) Extreme degrees of undefinability tend to lengthen perception of time.

4) The “re-fusing” (texture returned to timbre) of an undefined texture tends to neutralize the effect of lengthening the perception of time.

5) A very narrow ambitus tends to lengthen the perception of time. A wide ambitus, by itself, does not seem to affect this kind of change. In combination with other parameters, however, a wide ambitus may provide enhancement and space for other “time-lengthening” parameters to be effectively carried out.

6) A very narrow ambitus, when it follows a wider one, strongly lengthens the perception of time. A narrow ambitus, when preceding a wider one, loses the effect.

7) Extreme degrees of departure from a normative state may tend to lengthen perception of time, especially when there is effect in multiple parameters simultaneously (such as dynamics, register, speed, tonal direction and complexity). The more extreme the departures, the more time is perceived as lengthened.

8) Lack of tonal directionality in harmonic patterns tends to contribute to the lengthening of the perception of time.
9) All the above principles may work in an accumulative fashion; layering any number of the parameters cited above will contribute to an enhanced state and further lengthening of the perception of time.

10) We may call this super-enhanced phenomenological state, where a number of such parameters are working collectively and simultaneously to effect the lengthening of time, “supersaturation”.

7. Conclusions and Future Work

These findings have been followed up by analysis of contemporary musical works (Gyorgi Ligeti, Charles Ives, Stephen Horenstein). This researcher also plans to continue to develop concepts of time perception to help understand musical works, as well as develop tools for composing. Of special interest are musical phenomena which shorten the perception of time. Future studies will be complemented by use of MRI and other medical technology to try to further verify the effects of various musical experiences on the perception of time. In addition, the researcher seeks to develop a general theory of perceived time and music, as an analytical and compositional tool allowing for holistic approaches to diverse styles of music.

8. Acknowledgements

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References


Cohen, D. (2000-2001), conversations with the author, Israel


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