Music as strategy for memorizing objective time

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Abstract

In this paper the human ability for absolute timing is investigated. Although humans are very capable of performing tasks that require precise timing, such as walking and talking, we are not able to reproduce abstract timing intervals from (long-term) memory with great accuracy. In contrast, most of us are able to recollect our favorite musical pieces from memory, with only slight deviations in tempo. This suggests musical cognition and musical memory are somehow different from cognition and memory for other stimuli, and musical memory stores objective temporal information in higher quality.

In this paper, the hypothesis is investigated that musical segmentation strategies are helpful in accurately reproducing and comparing timing intervals. First, relevant literature for human cognition and memory of time is summarized, and secondly a computerized experiment is set up to compare the performance of participants using different time segmentation strategies.

While previous research seems to suggest musical cognition is able to encode representations of objective temporal information in higher quality than other types of cognition, in the performed experiment no such effect is found. The segmentation strategy that makes use of music performs worst compared to the other strategies tested. Interestingly, differences in performance for each of the segmentation strategies are found, and all strategies are beneficial compared to not using a conscious strategy. This suggests different types of memory encoding of temporal information are performed using each of the strategies.

Index Terms: ***Time perception, temporal memory, musical memory, interval estimation, segmentation strategies.***

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1: Introduction

The human sense of time is different from the other senses. Although we have some notion of absolute time passing, without something external to relate time to, the sensation of time passing seems to be very relative and subjective. Cognition of time seems to be less based on perception and more on abstraction. Historically, we have used reoccurring cycles in nature to objectively communicate about time (e.g. sunset, lunar phase). Since the invention of clocks, we have used a formal system (SI) for referencing our sense of time. It seems almost impossible to think about time passed without using certain external references, let alone making approximation of absolute time that has passed.

We remember longer periods of time by logically abstracting duration from events, which have a more or less known length of time and chronological order. We form a narrative framework, to which we can relate and approximate moments in, and intervals of time.

When asked to reproduce short timing interval, most of us seem to use the strategy of counting along seconds. This way an interval of time is segmented into smaller portions. Many researchers recognize a distinction between perceiving intervals above and below approximately 1-2 seconds, and suggest that the processing of smaller periods of time is sensory based, or benefits from some sort of automatic processing (Grondin, 2010). The estimation of longer periods of time is believed to require involvement of different, less precise and more conscious cognitive resources. When counting along seconds, the total time of the interval is segmented, translated and saved into a semiotic memory (e.g. 43 seconds). To reproduce such an interval, the process is reversed. Although this strategy gives us a way to more or less objectively remember a period of time, this process is prone to errors and takes of a lot of concentration.

Considering the problems we have objectively remembering timing, it seems amazing how accurately musicians can reproduce songs from memory. It can be argued that sound is nothing more than air pressure changing over time, and most qualities of music, like pitch, timbre and rhythm, are temporal patterns. The majority of humans posses the ability to recognize and differentiate between certain pieces of music and even between different artists or performances, apparently comparing the music with representations of previous encountered sounds in memory. Furthermore, recalling musical pieces seems to take place automatically and effortless, sometimes even involuntarily.

The fact that people are able to recognize, and reproduce music, points to highly accurate cognitive system for remembering timing. This seems contradictory to our difficulty remembering timing intervals of non-musical stimuli. Such a difference between performances would suggest that cognition of stimuli in a musical context is somehow different from stimuli without this context. It seems that the structures present in music allow time intervals to be remembered very precise, with minimum effort and less dependent on psychological factors.

This research tries to see if this musical cognition can be actively used as a strategy for gaining sense of “objective timing”. I will investigate this along the question**, ‘***Can a musical context be used as a segmentation strategy for accurately reproducing timing intervals?***’.** To this end, I will give an exploration of relevant theory on human time perception, and the memorization of timing. I will also elaborate on research done in the field of music in relation to timing and memorization. Furthermore, a computerized experiment is conducted to compare performance for segmentation strategies based on music, speech, and counting.

2: Theoretical framework

In this chapter, I will mention relevant literature for studying reproduction of objective timing, and the effect musical structure could have on performance. This part will be structured in subsections, trying to explore alongside four distinct questions; '*what is time?*', '*how does human time perception work, and how is timing information stored in memory?*', and '*where in the body is timing perception performed?' and 'what is music, and what could make musical cognition store objective temporal information in higher quality?'.* It is by no means my aim to answer these questions, or be all exhaustive in reviewing literature, but instead to find which factors are relevant and should be accounted for in the design of the experiment.

2.1: Ontology of time

Before trying to understand time perception, it seems important to take a detour and try to understand the being of time itself. Although the definition of time, falls outside the scope of this study, I will highlight some thoughts about the ontology of time, if only to show that the metaphysical being of time is less clear than it feels on first notice to us. Questions regarding a definition and ontology of time were mainly tried to answer by scholars in the fields of physics and philosophy. I will subdivide this part by separately describing time as a metaphysical being and as a phenomenological object.

2.1.1: Metaphysical view of time

All known substances in the universe seem to be influenced by the passing of time, although in a different, distinct fashion. Things grow over time, and things decay and break down over time. Isaac Newton described time as continually flowing onwards, without being influenced by external forces. According to Newton, every physical phenomenon takes place at a certain place and a certain time, both of which are part of an absolute reference framework of reality. In other words, Newton saw time as an independent fourth dimension. (Newton and Huygens, 1987)

In a standardized environment, there can be formed certain rules about the speed in which processes we associate with ongoing time, take place. This is the way we talk about an "absolute" time, calibrating passed time to the known static periods of these processes. However, it seems possible to influence the rate by which processes take place for certain things. By freezing an organic compound, for example, the effects of time can be withhold. Other events and processes, we associate with signifiers of ongoing time, can be speed up or even be reversed. This calls for the question if time is indeed a universal force, working on all substances equally, or that time could simply be a secondary effect, relative to environmental factors, we come to experience and describe as being a separate dimension. In other words, is time more than the temporal framework we create by watching these processes unfold at a certain natural rate and in a certain natural order?

9believed that an absolute time existed to which all durations related, but still recognized it was unseen, with humans only able to observe relative time (1687). Others have argued that there is no need for an absolute reference in the form of an encompassing "fabric" of time, and instead argue all that may exist is relative duration. For example eighteenth century mathematician and philosopher Gottfriend Leibniz saw the concept of space to only have meaning as the relative location of bodies, and time to exist only as the relative moment of bodies (Ferraro, 2007). This turned out to be a very influential thought within the debate about the ontology of time.

Time as movement

If we do regard time as an effect instead of a separate dimension, it can be argued time is always related to movement. What we experience as the passing of time comes down to chemical reactions, to the transfer of energy between states, thus the movement of particles in space.

As the scholar Theodore Bachelet described this relation in 1876*, ".. the notion of movement is closely bound up with the notion of space-time, " All motion takes place in space; it determines space itself [..] All motion also takes place in time and constitutes a succession of it; it is through the divisions of movements that we mark the divisions of time. Not only is motion the sign and the measure of space and time, but it is also the link between these two ideas in our mind "(Bachelet, 1876). "(Tordjman, 2011. P. 140)*

All technologies of keeping time in use by mankind, in some way or the other, are based on the movement of particles (f.e. movement of pendulums, springs or atomic decay), calibrated to an arbitrary mental framework, which in turn is based on reoccurring planetary motions -like days, months, seasons and years.

Accepting a notion of time in relation to movement, would also entail that total inertia of particles would mean stopping time. Cooling down a substance to approximating absolute zero would bring this effect about, practically stopping all motion and causal interactions. However, we would not say we have stopped time; we only stopped the working of time within the frozen substance. This way separate temporal dimensions are created. One within the substance were time is not progressing, and outside of the substance a dimension at which normal temporal continuity is preserved. French psychologist Sylvie Tordjman describes this as follows in her paper 'Time and its representations: At the crossroads between psychoanalysis and neuroscience'; "*The motion of a body is, indeed, not time, if we characterize it using an indicator that belongs to a different temporal dimension (i.e. one that is independent of that body's motion*" and she concludes, "*A body movement taken as a reference will be central to the temporal dimension it defines; if that body stops, time in that specific dimension will be "suspended" or "frozen", even though it continues to flow in other temporal dimensions.*" (2011. P.139).

When regarding time as an effect of movement, separate temporal dimensions are created with every process or movement, and the rates at which time progresses are dependent on the temporal dimension that is taken as a point of reference. To again quote Tordjman; "*We should never loose sight of the fact that there are different temporal dimensions, depending on our choice of point of reference, and each of them is therefore subjective. Each one of them belongs to a coherent system with it's own indicators which can be applied to another temporal dimension with extreme caution. It follows that as these indicators relate to their own particular temporal dimension only, they cannot be used as absolute references*"(2011. P.139).

Ernst Mach, in the nineteenth century defined the nature of time as the '*presentability*' (Darstellbarkeit) of all physical phenomena by each other (Debru, 2006). Although this definition on first glance seems rather vague, it does hold some truth. Timing seems to be the only property that can be assigned to all events, and therefore time does present us with a framework for regarding the universe, although this framework in itself is not physical. The fact that it seems as if there is a universal absolute flow of time, is then the effect of the complex web of constant referral we use in our mental frameworks of chronology. The use of events or reoccurring cycles for reference that are larger than our personal experience and longer than our lifetime, further emphasizes the sensation of time as a continuum. Examples are planetary orbits, or the theory describing the big bang and the following expansion of our universe - which some regard as the beginning of time.

A seemingly fundamental property of time seems to be the direction of causality. Events in the past influence the state of things in the future, but as far as we can grasp, not the other way around. However, it may be that this is only an effect of the linear way we experience our own being. When regarding the passing of time as the movement of matter in the universe, this property could break down, since all states, very theoretically, can be reversed.

Generally accepted is the view of Albert Einstein, who in 'special theory of relativity' described the relation between time and space (2003). In this theory, Einstein theoretically proves the entanglement of space and time by showing the relativity of simultaneity. This statement says that it is not possible to absolutely prove two events occur at the same moment, if the events happen at a different point in space. Different frames of reference observe the events occurring at a different moments since causality can travel no faster than the speed of light. The order of events is thus depending on the perspective of the observer in relation to the events.

This shows that the Newtonian 'fabric' of time does not exist. There is no absolute time that binds all duration, but instead there exists only relative duration within a web of reference. In any case, humans have no sense for observing a fourth dimension of time (which does not exist or cannot be observed), but instead can only have a way of observing relative duration.

2.1.2: Phenomenologist view of time

Immanuel Kant saw time, together with space, as being a human intuition (1781). According to Kant, it is a special, already-present framework that allows us to make analytical deductions, which could not be possible without this a priori intuitive understanding of time. Kant argues time cannot be an analytical concept, but instead is something that is present to make sense of concepts; a spontaneous passive mental framework, fundamental for ordering knowledge. In other words, without a sense of time, it is not possible to have experiences, and so, gain knowledge at all. Time therefore cannot be a form of knowledge, since it must predate knowledge in the mind. (Kant, 1781)

We can recognize the universal tendency of human reasoning to order everything in a chronicled narrative framework by the fact that all historic cultures have a system for keeping a calendar of chronology, technologies of keeping time, and having a deep commitment for studying and preserving history. On a personal level, we also keep a detailed ordered chronic of our life's events in our memory, and spend cognitive effort ordering our memories in a timeline. Often we feel the need to document our personal history with pictures or tokens of the past. Calendars have of course have an everyday practical use, and a historic perspective helps use make sense of new information and gives us insight in causality, but more so, perception of time seems deeply entangled with our regard of our place in the universe and our sense of identity.

When taking a Kantian, strict phenomenologist view of time, it can also be argued the passing of time is the transfer of future to the past within the mind. The now is the point in between that can be 'experienced'. The perception of the future might be regarded as the projection of things to come, and the past is made up of representation in personal memory of events experienced, as well as a mental framework of causality in which we order states encountered in the present. To quote Sylvie Tordjman; "*There is a simultaneous representation in our consciousness of past, present and future. In fact, when we activate a memory of the past or project ourselves in the future, we are still and always in the present moment of a process of representation*." and she further explains, *"…how can we objectively measure time past in relation to "what is no more", or time future in relation to what is yet to come?" For that matter, how can we measure "what is not?" This appears impossible, unless the past or future relates to "what is" in an individual's own subjective mental representations (i.e. in his or her own psychic reality), based on perceptions and constructions (memories of the past, projections into the future) that belong to the present."(*Tordjman, 2011. P.137).
Thus the passing of time can be defined as the translation and migration of representations of stimuli to different parts of cognition, which are all actively actualized within the present moment of perception.

Regarding the simultaneous representations of past, present and future, the representations of stimuli of the 'actual' present seem distinct, more directly derived form the senses, without decay, and therefore more vivid and clear. In contrast, memories of past representations are not perceptually driven but instead take cognitive analytical effort to be recalled. Another obvious distinction is that only the present -or near future- representations can be influenced by our embodied self. Here it implicitly becomes clear, that time is closely related to awareness and consciousness. The sensation of consciousness has often been described as being aware and able to reflect, and act upon things. The activity of actualizing and ordering the past, present and future, strongly resembles this definition. Both the feelings of awareness and consciousness entail a sense of 'nowness', and experiencing these sensations outside of the embodied actuality only happens in dreams and hallucinations. This topic will be further explored in the next chapter.

2.2: Cognition of timing

Moving away from the open question of what time is, we return to the question of how human timing perception is performed. In order to set a context for the research question, and determine which factors to account for in the design of the experiment, it is essential to try to form an understanding of the characteristics and mechanics underlying human time perception. Or, as we determined in the last chapter, more precisely, the mechanics that allow humans to judge relative durations *within a mental framework of causality*. Various fields, like neuroscience, philosophy, (chrono-) biology, medicine and (cognitive and experimental) psychology, have studied the cognition of time, and there is a multitude of hypothesis as to how it is performed.

At this point I would like to mention that to this date, no clear consensus is reached about the underlying system of human time perception, and no clear evidence is found to dismiss or accept one of the described systems. One could say that, to a certain degree, the precise mechanics of time perception are still largely unknown. That being said, a lot of compelling theories have been set forth, and many efforts have been made to measure aspects of timing cognition. As I will argue, the reason why it is hard to find discriminatory evidence for one of the theories might be that there is no single system for time perception. Instead, there could be a multitude of systems cooperating and complexly interacting, and certain tasks could have an agency for triggering several systems to a bigger extend. (Peretz& Zatorre, 2005).

In this part about cognition of time, I will give an overview of historic and recent thought about the human capacity for time perception.
First, I will elaborate on the concept of the *specious present*, since in my opinion it shows an important theme in perception of time and time perception research.
Next, I will explore the most important psychological models used for understanding the cognitive mechanisms for timing behavior.
Furthermore, in the follow-up chapter, the objective temporal properties of the body will be discussed, that is to say, which physical organs could lie at the base of estimating timing.

2.2.1: Specious present

I have already mentioned that there is a close relation between perception of time and consciousness. In the chapter on the phenomenologist view of time, we saw that 'the now' holds a special position in perception of time since all timing representations (of the past, present and future) must be actualized through/in the moment of the present. This process is closely related to the concept of consciousness, which could be seen as being aware, and able to think and reflect upon things. In this part perception of the *now* will be discussed.

Our representations of time are all made up of grainy absolute units, however we perceive time itself as "*a stream and uniform dimension leading to a continuous sense of time.*"(Tordjman, 2011. P.139) A human has the impression that "*physical time is a continuous flow that can be divided indefinitely into smaller units* "(Grondin, 2010. P.564). If we take this view of the passing of time as a continuous gradual migration of the future to the past, the now must be infinitely small. The smallest thinkable time that has past, no longer belongs to the present, and the same holds true for the smallest possible time unit still in the future. This leaves no duration of time for the present.

However, if in our mind the passing of time is the migration of representations of time to distinct parts of cognition, all being actualized to form consciousness, the perceptive present cannot be infinitely small. Consciousness is a cognitive activity, and therefore takes up time to be performed. There is latency; a delay between stimulus perception and cognitive consciousness, and it takes time for stimuli to be processed and to be grasped. Furthermore, to see proximity or causality, certain stimuli are connected into one coherent whole, for example when we form a mental scene from the two separate images from our eyes. We constantly form continuity from discontinuous stimuli. This automatic sensory reduction can be seen as a summing or folding of time. In psychology, a similar effect has been coined *temporal binding*, and is defined as a "*subjective contraction of time that elapses between an action and a delayed sensory consequence of it*" (Repp,2011. P.491). Thus, while the flow of time might seem to be able to be 'divided indefinitely into smaller units', a single moment in our mind actually must consist of a certain period of time.

In the nineteenth century, Scholars like Johan Friedrich Herbart already began asking the interesting question of the amount of time that can be simultaneously grasped by the mind. The answer could be a sort of psychological unit of time. Instead of trying to directly define a static duration for such a grain of time, Herbart describes a model of perceptual time in relation to the effect he calls inhibition, "*the effect of the arrival of new representations on preexisting ones in consciousness*" (Debru, 2006. p331). He describes that in the absence of a new stimulus, the representation of the preexisting stimulus keeps occupying the mind for a period. In his proposed system, inhibition increases over time so new stimuli take over perception. Determinate for this period is the intensity of the preexisting stimulus, whose function decreases exponentially over time.
So in other words, the intensity of the stimulus determines how long it prevails over the growing effect of inhibition. According to Herbart, the increasing of inhibition makes time perception possible. In 1839, looking at the exponential

curves he measured, Herbart estimates that the amount of time that is best perceived in consciousness is approximately two seconds. (Debru, 2006)

Gustav Theodor Fechner makes a similar proposition in 1860. For time perception he uses the analogy of the space sense of the skin, studied earlier by Ernst Weber. Weber found that the resolution of sensing spatial stimuli on the skin is not indefinite, but organized in circles. Touch within the diameter of such a circle is perceived in the indiscriminate manner. The minimum diameter of these circles therefore defined the subjective measurement of space. Fechner noticed that, similarly, multiple sensations in close temporal proximity merge, making it unable to perceive them separately. Fechner explained this by sensations having a 'Nachklang' or aftereffect (this can be regarded as being closely related to Herbart's *inhibition*), which if still strong enough inhibited a new sensation of being differentiated. Therefore a period existed in which no time sensation occurred. (Debru, 2006)

Such a period of time, approximately in the range of one to a few seconds, is very often mentioned as distinct in timing research, especially in the field of neuroscience. William James, in 1890, coined the term *specious present* to refer to the phenomena of an optimum of time people are able to grasp- although he found a longer interval of three to four seconds (Debru, 2006; Tordjman, 2011). Simon Grondin speculates to the basis effect; "*the processing of smaller intervals is sensory based, or benefits from some sort of automatic processing, whereas the processing of longer intervals requires the support of cognitive resources*"(2010. P.564). This notion of the sensory based 'experienced' now, versus the cognitive abstracted past time is an important notion for understanding the mechanics of interval estimation.

2.2.2: Duration based accuracy and segmentation strategies

Not only is the period of the *specious present* recognizable as a cognitive distinction, it can also be measured when looking at the effects of certain pharmaceuticals and experiments with the accuracy of timing estimates. (Grondin, 2010) Many different phenomena have been measured within the few seconds interval, and although all show somewhat different lengths, all are intervals below one second. Examples are optimum values found for the indifference interval (700ms), the preferred tapping tempo (600ms) and the highest sensitivity for tempo discrimination (300-800msec). The duration of a few seconds therefore seems to reflect some "*fundamental transitions about the way the brain captures information.*"(Grondin, 2010. P. 564).
It can be said variation in accuracy of timing estimations is duration specific, and that different categories of intervals of timing probably are processed using different forms of cognition, with representations of intervals below approximately one to a few seconds being less subjective and more precise.

Of course it is to logical to presume, with every system of timing, within shorter interval there is less change of deviation, but for human perception of longer intervals there seems to be no system that is linearly related to objective referenced time. Instead time perception for longer durations seems to be only based on external stimuli and cognitive deduction.

As mentioned in the introduction, humans adopt strategies to make use of this more precise estimation of shorter durations while perceiving longer periods of time. These strategies are called segmentation strategies. "*The aim of a segmentation strategy is to divide a given interval into smaller usually equal portions*"(Grondin, 2010. P.564) Instead of directly estimating a longer interval, the amounts of smaller intervals present in a given period are counted. This way longer intervals can be perceived more objective, using the more time sensitive cognition of smaller periods. The most commonly adopted strategy of counting does seem to require a lot of concentration and attention. When using a strategy of segmentation the longer interval is not measured and memorized as timing information, but instead is translated to a semiotic value, in the case of counting a number. Storing only a semiotic value is efficient, but in itself does not store temporal information.

Summarizing, we can argue that it might be, that the only way we truly perceive or experience time without an external reference is in the duration of the so-called *specious present*. Although we form representations of longer timing intervals, they seem to be mostly derived from analytical cognition in correspondence with regarding external signifiers of timing, or to be made up of summing intervals that can be perceived in the moment of the specious present.

Another finding that might be worth mentioning here is that timing perception seems to be duration specific. This entails that different accuracy biases have been measured in different ranges of interval estimation (Grondin, 2010). This suggests that besides the phenomena of the specious present, more different distinct timing systems can be activated, according to the duration range in which the behavior falls.

2.3: Objective properties of the body

Although we saw that time itself may be relative, and perception of time subjective; judgments of duration are partly based on objective physical properties – although as noticed before, perhaps only those on shorter durations. Somewhere in our body, there is a mechanism at work that allows us to make time estimations with, at the very least, a higher accuracy than guessing intervals at random. Sylvie Tordjman describes the relation between concepts of time and the objective mechanism as follows; "*Representations of time and time measurements depend on subjective constructs that vary according to changes in our concepts, beliefs and technological advances. Similarly the past, the future, and also the present are subjective representations that depend on each individual's psychic time and biological time. Nonetheless, the construction of these representations is influenced by objective factors (cognitive, physiological and physical) related to neuroscience. Thus, studying representation of time lies at the crossroads between neuroscience and psychoanalysis*. "(2011. P. 137). In this part the objective properties of the human body involved in timing perception will be explored.

2.3.1: Mechanisms for time perception

One of the main questions time perception scholars have tried to answer is which mechanism and corresponding parts of the body are responsible for our system of estimating timing. The main debate has been on whether we posses a special dedicated organ used for all time-sensitive tasks, or that time estimates are made using more general systems of cognition. So in other words, can we locate a certain system or organ that has mechanics that explain time perception (a central clock), or can the skill we have of estimating time be explained as a function of general intelligence, in combination with our embodiment. A third option, that resembles modern findings in other topics in the study of cognition, is a hybrid theory that suggests that there are multiple specialized systems activated according to the nature of the timing task.

The discussion about whether cognitive skills can be explained by general cognition or only with dedicated biologic mechanisms is not exclusive to time perception research, but instead can be seen as a central question of cognition research in general. It is very related to the general nature versus nurture theme in biology research. The two opposing paradigms, for example, can also be recognized in the field that has studied cognition of language (for instance in the work of Noam Chomsky (2014). In general, this debate can be summarized by answering the question if the behavior observed can be accounted for by decision making on the basis of purely statistical computations on sensory data (statistical learning), or that some specialized system of cognition is needed to explain the observed efficiency.

Logically, it seems clear that the brain and general intelligence play a large part in the deduction of timing, especially as practiced for larger intervals. In human sensory cognition, a system is made up of the sensor, the nerves, and the brain (some parts more than other), all determining the nature and quality of perception. As made clear in previous parts about the ontology of time, there seems to be no dimension of time that can be referenced, and thus timing cognition doesn't seem to rely on a separate sensory organ, which directly provides stimuli derived from an external object of time. If we see time perception as *judging relative durations within a mental framework of causality*, a definition we put forth in the beginning of this chapter, all senses play a part as external temporal reference and as signifiers of causality. However, as discussed, we do also make use of internal time-sensitive mechanics to objectively 'sense', or better experience, duration without the need for external stimuli. We somewhere have a body part that allows us to tell, in sensory deprivation, the difference between approximately two and thirty seconds. The discussion between the paradigms of the *dedicated organ* versus time perception as a embodied *cognitive function*, is on the mechanics and location of the objective time-sensitive part of the system used to estimate interval duration, the so-called *clock*. In the way the sensory systems and the higher brain cognition work together to allow for auditory perception or visual perception, such a clock device would work together with general cognition to allow for timing perception.

In the next part I will first describe some proposed models used for understanding the mechanics of time perception. Secondly, I will explore what could be the physical location in the body for the system of time perception by discussing research and findings related to this matter. Note again that there are a multitude of varying models set forth, all with different nuances, and that the distinctions made in this chapter are not meant to form a taxonomy of models, but instead point only to categories of resemblance. Interesting is that some models explain certain types of behavior well, while others are better at explaining different time sensitive behaviors. This might point at the existence of multiple mechanisms collaborating in time cognition, being triggered by the expectation of the task at hand.

2.3.2: Models

Dedicated systems view

The longest tradition in thought about time perception has been the view of a dedicated device for telling time. This paradigm supposes we have a specialized mechanism we use for all time-sensitive tasks. This mechanism could be referenced when needed, like having an internal wristwatch. Indifferent of the sort of timing task, a signal from this device is used to organize behavior in time, for example timing muscular movement when walking or talking. This would be opposed to having distributed systems singular to each behavior, or as we will see later on in this chapter, relative systems that explain human timing without the need for a clock. The proposed mechanics of a specialized device can be seen as falling into two main traditions; the pacemaker-counter models, and the models based on oscillator motions.

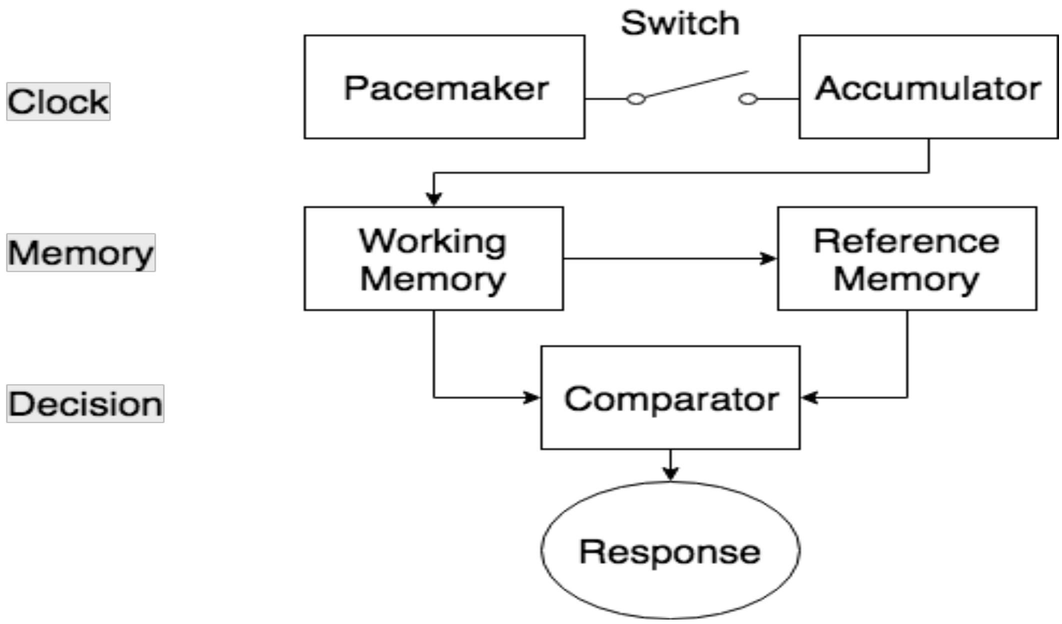
Pacemaker- Counter models

The earliest and most established type of models that have been proposed, see the system for making time estimations as an organ that functions resembling a timepiece based on a quartz crystal-technology. These models are called *pacemaker-counter model*s. The pacemaker provides a discrete signal at a regular interval, and counting and summing these pacemaker-pulses can time an interval. This unconscious process on a lower level would strongly resemble the conscious segmentation strategy used for gaining sense of longer intervals of time described earlier. Although such a system is simple, it can explain most observations related to human and animal timekeeping.

One of the most dominant contemporary theories on behavior timing, based in this paradigm, is the *Scalar Expectancy Theory* (Gibbons, 1977). *SET* and most other psychological models within the pacemaker-accumulator paradigm, argue that timing behavior involves three levels of information processing. These three levels can be recognized in the descripting of time perception by Allan and Kristofferson; "*the input is thought of as one which takes a measure of the temporal extent of a stimulus pattern, compares the measure either to an internal standard or to the memory of a measure of a standard stimulus, and triggers a response, which may or may not be biased, depending on the outcome of the comparison process*"(1974).

The pacemaker-accumulator model dynamic, based on John Gibbons theory for non-human timing behavior (1977), is shown in a diagram in figure 1. When the timing of a process starts, the 'switch' is closed, and the amount of clock pulses is summed in the accumulator. The value of this accumulator is constantly being send to a location in working memory. This value in working memory is then being compared to a relevant reference count from memory representing an expected timing count (for example a previously encountered time a process continued). The comparator computes a ratio of the current value set to the reference value and when the comparator-ratio crosses a certain threshold, a decision is made which behavior will be undertaken in response. (Gibbon, 1977; Grondin, 2010; Tordjman ,2011)

Model of time perception based on Church and Gibbons (1982) – the Pacemaker Accumulator model (Tordjman, 2011. P.141)



Since this systems works with the comparator computing a ratio, instead of for example producing an exact difference in counts, the precision of the system is scalar instead of absolute. The longer the interval that is timed, the larger the absolute margin of error becomes. This observation gave this model its name.

The fallibility in estimating time within the *Scalar Expectancy Theory* can be related to four categories of errors: a *pacemaker error*, a *switch and marking error,* a *counter* error, or an error in the *memory and decision process*.
The unreliability of the counter is according to most researchers, the common cause for timing errors. Instead of a fixed regular pulse, the signal is often supposed to have stochastic elements. There has for example been speculated the frequency of the pulse is influenced by arousal. (Grondin, 2010)
Counter errors are less mentioned as source for timing errors. Some mention has been made about the system a counter would use and how this would affect timing accuracy. Counting in a hierarchical system, like binary or decimal, would make "*the magnitude of timing errors increase disproportionately each time the next stage of the counter must be set*"(Grondin, 2010. P.569). Missing a count can then affect the accumulation by a factor, instead of by the value of a single clock pulse. A switch and marking error is argued to be associated with mechanisms of attention. In dial-task manipulation, it is shown that when full attention is paid to the passing of time, the estimations are the most accurate (Macar et al., 1994). The last type of errors mentioned, are faults to due with the memory and decision process. These fault could arguably be seen as not belonging to the lower timing system, but instead be part of the higher level cognitive deduction of time. In the case of a memory error, the comparative value for the accumulator value is wrongly represented in or retrieved from, memory. (Grondin, 2010)

Oscillator models

The second major distinct tradition in the dedicated systems view of timekeeping is a category of models based on oscillating systems, instead of pacemaker clocks. The technologic equivalent analogy of such a system would be a clock based on a pendulum. Within such a system, timekeeping is not performed counting discrete and absolute pulses, but rather on phase discrimination within one, or multiple, oscillatory waves. Theories based on oscillating motions are attractive because, unlike discrete clock counters, many such systems can be naturally observed within the body's biochemistry and neurology.

Entrainment

These types or models in general seem better quipped for explaining timing behavior within a regular temporal context. This is mostly because in most of these proposed systems (but not all), the internal reference pattern is dynamic. In the pacemaker counter models, we saw the frequency of the clock signal is fixed- or only influenced by internal psychological states, like arousal. In most oscillatory theories, the frequency of the oscillatory reference signal can be attuned to the environmental temporal patterns observed. When the environment contains longstanding temporal regular patterns, the frequency of the internal oscillator can be equally matched. Thus, in these models, a representation of an external temporal pattern becomes internalized by a rhythmic resonance within the body. This effect is called *entrainment*. This makes timing on the basis of expectancy within a regular predictable environment more accurate. However, it makes it problematic for these models to account for the referencing of information about the timing of events from memory. With a dynamic reference pattern, it seems impossible to compare timing to timing encoded in memory, which was saved when the reference pattern was oscillating differently based on a different temporal environment.

Other theories based on oscillators instead of pacemakers, but without a dynamic reference frequency pattern, make use of multiple, frequency-fixed, oscillating movements in the body for referencing time, and claim we use different combinations of signals, selected according to the length of the interval that needs to be timed. Signals sources that are being mentioned here are, for example, circadian rhythms of hormones, that fluctuates under the influence of light.

Description of DAT

The most mentioned within the paradigm of oscillator theories, and the basis for many other theories in this field, is the *Dynamic Attending Theory* by Jones and Boltz (1989). This theory has a primary role for the psychological factor of attention. In DAT, attentional energy is directed in momentary pulses that form attentional oscillating rhythms on the basis of external temporal structures. In this model, it is these rhythms of attention that allow for timing behavior based on expectancy. Such a model would explain why we rely so heavily on external stimuli to determine timing, and why the process of cognition of timing takes extensive concentration to be performed. Large and Jones describe DAT as follows; *"….the dynamic attending frameworks postulates two entities: external rhythms, which are created by distal events, and internal rhythms, which actively generate temporal expectancies. It also postulates a coordinated relationship between these two entities that arises as a result of entrainment*"(Large and Jones, 1999. P. 123)

Memory encoding of temporal patterns versus dynamics of attending

The dynamic attending theory is a combination of theories that deal with the encoding of temporal patterns in memory, and theories that describe the dynamics of attending in vision. Together they form a theory of how attention is selectively directed across temporal sequences. Large and Jones mention how visual theories describe multiple forms of the capture of visual attention, and that it has both a goal driven, deliberate components, which direct gaze according to long term goals and expectancies, and a stimulus-driven component, in which external stimuli actively capture and direct attention (1999). They describe attending to temporal sequences is also based on both deliberate internal mechanism of expectancy, and on external structures present in the sequence rhythm of stimuli. Both interact by means of entrainment. (Large and Jones, 1999) This way "*temporal expectancies are instantiated as the behavior of internal rhythmic processes*"(Large and Jones, 1999. p.123).

Self-sustaining oscillations

Both the internal rhythms of attention and the external temporal structure can be modeled with means of self-sustaining oscillations. According to Large and Jones; "*A self-sustaining oscillation has two important features that make it appropriate for modeling the basic process of attentional dynamics. First, it generates periodic activity, an activity we refer to as expectation. Expectations are similar to the ticks of a clock, with the important exception that an expectation is an active temporal anticipation, not a grid point in a memory code. Second, when coupled to an external rhythm, a self-sustaining may entrain, or synchronize, to that rhythm. Therefore unlike a fixed clock, synchronization between an attending rhythm and an external rhythm is stable, meaning it is robust to both random and non-random perturbations of the external rhythm. Finally, an attentional rhythm may adapt its period in response to systematic rate changes in an external rhythm. Thus an attending rhythm adapts to meaningful temporal fluctuations found in everyday events.* "(Large and Jones, 1999. P.124)

The complex external temporal periodicities found in natural phenomena like speech and music, can thus be perceived with the mechanism of several internal oscillators resonating alongside the various timescales present in the temporal structure of an external stimulus signal. In the DAT, these internal resonating oscillators would allow us to expect certain patterns in time, and display behavior in anticipation of events.

Additions to DAT

In human timing cognition some biases in time discrimination can be found, with some timing behavior being more likely than others. Examples are the aforementioned *just noticeable difference* and the *preferred tapping tempo*. These phenomena have been used to argue for certain ways of statistical or counter memory encoding of time. This seems to contradict the proposed dynamic properties advocated in DAT. In the dynamic attending theory, however, these characteristics of timing behavior can be accounted for by the idea of certain oscillators with a preferred period. Such oscillators are more likely to harmonize with certain frequencies over others.

Emergent cognition/ no central clock

A distinct paradigm of models is formed by theories that argue there is no need for a specialized system to explain timing behavior. Instead, researchers in this paradigm propose we make use of the statistical mapping of time-sensitive phenomena within our body. This entails that a less dedicated, more general form of cognition is used to analyze and link time-sensitive processes to relevant semiotic signifiers. A simplified analogy for such a system of learning timing behavior would be a Pavlovian training method; when a bell is rang, it is time for dinner. In such a system, stimuli that always appear in proximity of each other become meaningfully connected. In most of such systems, next to external signifiers of ongoing time, behavior is also directed using internal temporal signifier systems. Several bodily systems are said to be time sensitive, which means that a certain process takes a more or less fixed time to be performed, and thus could serve as an unit of time.

Motor-feedback models

An interesting idea within this paradigm is behavior timing based on muscular feedback loops. Within such models communication within the muscles, and the returning feedback that is generated by movement, functions as a timing system. Examples of motor-feedback loops, in these cases closed, are reflex responses. We talk about a reflex when behavior is automatically performed on the basis of a certain stimulus. Such more or less automatic responses of the muscles to sensory stimuli play an important role in motor control. The timing of muscle contractions is often based on the feedback of different muscles, and such the human motor system in any case plays a role in the timing of behavior.

More conscious timing behavior could also be performed in this manner. If, for example, we would consciously try to follow a beat by tapping along, we could tap once and determine we are tapping to late. We could then determine the strength of the feedback from the muscles for the last tapping movement, and map the auditory stimulus of the beat to this muscle feedback intensity appropriately. For the next tap, we would send a signal for the next muscle contraction, before the feedback decays to the strength we encountered before when the auditory stimulus indicated the beat, therefore tapping earlier. This way, after a few tries, we would be able to establish a proper on-beat feedback loop. If we are able to time movement this way, it might even be possible to time more abstract intervals this way, even without actually moving consciously. Timing could then be performed by unconsciously establishing feedback loops for timing intervals within a structured environment, or by comparing current muscular feedback with decay patterns stored in memory.

There is some compelling evidence for the important role motor-feedback plays in the timing of behavior. For example, in experiments with participant performing different motor tasks, different regular timing biases have been observed. This indicates that different motor tasks make use of different, perhaps dedicated, timing systems. (Grondin, 2010) It is also observed that tapping along with a musical rhythm improves on-beat behavior timing, compared to not moving along (Manning and Schultz, 2013). This indicates an attentional emphasis on movement improves or strengthens timing accuracy.

Speculating, one might come to the conclusion, that actively performing motor movement, if not being the locus/source of timing, at the very least activates an extra timing system.

Neurological patterning- state neural networks

A different, but very related view, is a model of timing behavior based on neurological feedback loops. The speed of electrons travelling to neural fiber has a fixed velocity, on the basis of some factors like temperature. Sending signals along the fibers of a known length, discrete units of time can be derived from the feedback. Each fiber could then represent a measure of time, and with many different neural pathways available, different intervals can be mapped. In 1850, Hermann von Helmholtz already started the discussion of the relatedness of the temporal properties of the nervous systems and time perception, by measuring the transmission velocity of the impulse in the nerve (Debru, 2006).

Another different way of modeling the manner in which neurons could be used for timing perception is referred to as *state-dependent networks*. Grondin describes that in such models "*Timing does not depend on a clock, but on time-dependent changes in the state of neural networks. Durations are represented as spatial patters of activity, and judging durations means being able to recognize these patterns.*" (Grondin, 2010. P567) The character of such a system is different to a clock, or a simpler feedback system, in the way that there might be no proportional, scalar relation between different temporal aspects, and that for example two different pitches might lead to representations that are inexpressible in relation to each other. This in the same way as frequencies of light can have a mathematically relation to each other, but the psychological sensation of colors is less proportional and more categorical -in the sense that two times blue doesn't make red, and there is no direct scalar relation to color sensations in perception. The way in which the neurological system reacts to stimuli could be very different and unique for different temporal stimuli, and recognizing these emerging patterns could lead to a system of interval discrimination.

Peter Cariani (2001) describes how traditionally auditory perception is viewed as being a running spectrum analyzer, in which sound is translated into stimuli by analyzing the frequencies of the incoming sound. The outcome of such a harmonic filter is deducted into for example temporal onsets, used as input for dedicated or central cognitive systems for timing. Simply said, this way an auditory signal is first filtered based on temporal attributes we see as belonging to sound texture before larger temporal structures are analyzed and recognized. Interesting about timing theories on the basis of spatial patterns in neural networks, is that they in effect propose a system without filtering. Instead, we recognize neurological states that are the result of all encountered temporal patterns -both attributes belonging to sound texture as well as larger structures like rhythm (Cariani, 2001). Where in clock and oscillator models, higher-order conceptual structures are formed by distinct higher-levels of cognition, in this paradigm of models, these all become part of a reactive perceptual auditory cognitive system.

Interestingly, such a holistic view of auditory perception would mean that in such a model, instead of the complex temporal patterns, rather the simpler temporal patterns are a deduction by higher order conceptual cognition. In this way gaining information from auditory systems is performed top-down instead of bottom-up. This seems less efficient, with fewer possibilities for making generalizations about auditory signals. However, pattern regularities do exist, and the neural reactions for simpler stimuli interact to form more complex patterns in a predictable manner.

Such a model for perception appears to leave the auditory perception a 'black box' due to its inescapable complexity, but perhaps future research would allow for modeling using high-resolution fMRI, perhaps in combination with computerized neural network simulations. In fact, this is the first model I describe here, that directly grounds auditory signal computation to physical biological mechanics. Examples of this type of research can be for example relating the cadence of discharges of the auditory nerve fibers to psychological perceptions. The firing patterns of the nerve fibers could for example be used to explain preferred tonal relations in music.

In my personal opinion, such a view of auditory perception feels better adept to describe the deep emotive and embodied response we have towards the combinations of temporal patterns found in music. In music, the composition can feel as more than the sum of the parts. Of course, this feeling is just intuitive and this effect could also be explained by the combined dynamics proposed in one of the other aforementioned models triggering a deep emotional response.

2.3.3: Physical locations of timing systems

The models without the need for a clock, described in the previous chapter, aim to directly connect timing perception to physical, biomechanical systems within the body. Within the clock paradigm such a relation remains more abstract. In this part I will briefly mention some of the physical bodily system that researchers have been able to relate to timing cognition, in an aim to show where the biologic mechanisms for timing are located. Although not directly crucial to the topic of this paper, looking at these relations does shed some light on which models can be seen as most plausible. Furthermore, some findings mentioned here suggest that humans are likely to involve multiple different systems in temporal cognition, and that the nature of the timing task at hand determines which systems are dominant at a certain moment.

Modality –specific perspective

One of the most important findings in timing research to date is that timing systems appear to be modality specific. This would mean different systems are used when, for example, estimating an interval based on visual or auditory cues, or at least timing cognition is closely intertwined with sensory perception. This conclusion arises out of the fact that specific attributes have been found in behavior based on different sensory modalities. (Grondin, 2010; Debru,2006) Such a notion would be in favor of models that use distributed cognition system, rather than theories based on a central timing system. Not only is this finding important for understanding timing perception, such an insight is also crucial for designing an experiment involving timing. It is widely been demonstrated that the auditory modality is able to trigger the most accurate temporal judgments (Grondin, 1993; Hatcher-O'Brien and Alais, 2011; Repp and Penel, 2002).

Brain structures

Logically, many researchers in the field of neuroscience, have tried to pinpoint which parts of the brain are used in timing behavior, and whether perhaps there are specialized structures that can be linked to certain timing tasks. Experiments have been done with the help of imaging technologies such as EGG, rTMS and fMRI. The foremost tool for investigating the mechanisms of timing behavior is EGG, since the temporal resolution of this technique is the highest. This way images can be more precisely correlated to behavior over time. In the coming year many new insights can be expected from fMRI, since latencies keep decreasing and it has a superior spatial resolution. Other scholars have tried to describe timing behavior changes as an effect of observed brain deficits. Research in this area can be difficult, since there might be personal differences in spatial brain activity, and within patients with deficits, brain plasticity can be responsible for redirecting resources. (Grondin, 2010)

In the next part, I will describe some brain substructures linked in distinct ways to timing tasks. However, the reader should keep in mind many questions remain open and surprisingly has little evidence has been found. As Teki and Griffiths mention "*perception of time is an essential aspect of human brain function necessary for performing coordinated actions including speech and movement. However the absence of dedicated neural machinery for temporal processing renders time perception an intriguing problem in neuroscience*."(Teki& Griffiths, 2014. P.1)

Cerebellum

Early on, the hypothesis was formed that the *cerebellum* was involved in timing tasks. This was based on the argument that time perception and time production task should be correlated. If perception and production behavior is related, it can be expected brain regions in close proximity of one another control them. The cerebellum is linked to many time-sensitive motor tasks, such as eye blink conditioning and perception and production of speech. Interestingly, involvement of the cerebellum in the temporal component of the task seems to depend on whether timing is discontinuous. In a continuous rhythmic context, the cerebellum seems to play no major task. It has been observed that lateral cerebellar lesions increase the variability of intervals when patients are asked to produce a series of taps. This deficit seems to be strictly related to timing since no general auditory incapacity is observed. In which interval duration range the cerebellum is active is much speculated upon but yet unknown, and different experiment arrive at different conclusions. (Grondin, 2010)

Cerebral cortices

Several areas within the cerebral cortices are linked to timing behavior. Especially the *frontal* and *parietal cortices* and the *supplementary motor area* are active when performing explicit timing tasks. The *dorsolateral prefrontal cortex* is measured to be involved in the processing of sub second intervals, and the *right hemispheric prefrontal cortex* both with sub and supra second intervals. The frontal lobe thus seems crucial in the coding of temporal information. Within this realm of investigation clear differences have been found on the basis of the duration of the interval that is expected. This shows expectancies produce feed forward brain patterns. The patterns differentiate not by there spatial locations but within the electoral activity measured. The amplitude of potential changes (*CNV's*) is said to reflect the accumulation of timing information. When adopting a pacemaker-accumulator model view, the potential could be regarded as a measure of the accumulated pulses.

The *supplementary motor area* as well, is linked to timing tasks within the sub second duration. It is also active during implicit counting tasks. Furthermore, the *right posterior parietal cortex* is found to be critical in sub second interval marked by auditory of visual cues. Images obtained by fMRI suggest that the parietal cortex acts as an interface between sensory and motor processes. (Grondin, 2010)

Basal Ganglia

The *subcortica*l cerebral structures of the basal ganglia are argued to be involved in the early stages of the timing process. They are said to specifically be involved in the encoding of time intervals. More precisely, the *caudate* and *putamen* parts are involved in this task. The right part of the caudate nucleus, and in some research the putamen, are related to both the processing of sub second and supra second intervals.

Dedicated clock circuits

Some speculation in the field of neuroscience went into which circuit could serve as the clock proposed in the dedicated clock view of timing cognition (both the pacemaker accumulator and the oscillator models). For example, Simon Grondin describes the model of a frontal-striatal circuit;
"The hypothesis is that striatal cells receive inputs from cortical neurons when a "start-timing" signal is given. These cells, which have firing rate from 10 to 40 cycles per second and are not normally synchronized in their activity, begin firing simultaneously for a moment creating a specific pattern of neural activity. When the timekeeping activity must stop after a specific time interval, the substantia nigra sends a message to the striatum. The pattern of activation at that moment is then recorded via a burst of dopamine and serves to identify a specific interval length. " (Grondin, 2010. P.573)

Circadian rhythms and other types of oscillating bodily functions

When one takes a view of time perception as seen in the paradigm of the oscillating clocks, one can speculate which sort of biological oscillations can be used as a frequency generator. Many types of oscillating systems can be found in the body, both electrical and biochemical. One of the most mentioned biochemical systems related to timing behavior are circadian rhythms. Hall, Rosbash and Young, who won the 2017 Nobel Prize of Physiology for their work did interesting research in this respect (2018). They were able to isolate a specific gene in fruit flies, responsible for their biologic rhythm. This gene encodes a protein (PER) in the dark, which in turn is broken down when the fruit fly is exposed to light. The level of this protein (together with the TIM-protein) forms an oscillatory pattern, with a phase synchronized to the earth's rotation. It is very likely that humans use a similar system to calibrate our circadian rhythms. These circadian rhythms without a doubt play a role in timing our behavior.

Interspecies comparisons

An interesting way of gaining knowledge about the location of the biomechanics involved in human timing perception –and in the context of this research, more specifically musical perception- is comparing our abilities and physiology to those of other species. Charles Darwin, in his 'Descent of men', speculated that, "*our capacity for musical rhythm reflects basic aspects of brain function broadly shared among animals*" (1871). Darwin felt like our sense and enjoyment of rhythm and melody was reliant on ancient and fundamental structures of the nervous system, and thus should be shared with animals with which we share common ancestors. From an evolutionary perspective such a stance seems logical; precise timing systems are beneficial in most environments, and survival seems unlikely without manners of timing behavior in correspondence with timing patterns in the environment. Moreover, periodic rhythm plays a part in many biological systems, such for example heartbeat, brain activity and motor timing. Rhythms are said to be "*intrinsic to the physics of the neural systems involved in perceiving, attending, and responding to auditory stimuli* "(Large and Snyder, 2009). Rhythmic behavior can be observed in types of frogs and insects, giving credit to Darwin hypothesis.

Actual experimental research, however, suggest that our capacity for timing and perceiving rhythm is mostly unique and only partly shared by a limited number of other species. Although "periodicity and entrainment seem to be among the most basic features of living things, the human ability (and proclivity) to entrain our motor outputs to auditory stimuli appears to be very rare"(Fitch, 2012. P.78). Rhesus monkeys (Maccaca mulatta), with which humans share a lot of DNA, are able to reproduce the interval between two metronome clicks, but have great difficulty in learning to tap in synchrony with multiple metronome beats. "*This suggests that their behavior was dominated by reaction rather than anticipation (although they did react more quickly to metronome events than to randomly timed events thus showing some modest anticipation abilities"*(Pattel, 2014. P.2). As well, different from humans, they show similar performance responding to auditory cues as to visual cues. This difference suggests behavior is governed by different systems. Research using EEG imaging also points towards differences in beat cognition between humans and monkeys, since monkeys show no "neural correlate of beat perception"(Pattel, 2014. P2). Chimpanzees (Pan troglodytes), are known to 'drum' in the wild. In experiments it has been shown that they can display the capacity for anticipatory synchronization, but it has not been shown they posses great tempo flexibility (Patel, 2014).

It has been suggested that our capacity for rhythmic processing coevolved with our abilities for language processing, which is also seen as a rather unique human ability. This makes sense because language computation, similarly to rhythmic cognition, requires analyzing and producing complex highly structured auditory signals. "*Vocal learning occurs in just three groups of birds (songbirds, hummingbirds, and parrots) and a few groups of mammals, including humans, elephants, and some cetaceans, seals, and bats [30-35]"(*Patel, 2014. P.3). Studies with birds show that vocal learning is associated with specialized neural circuitry in the forebrain premotor areas, the basal ganglia, and their connections The premotor and basal ganglia are also shown to be important in beat processing, which makes the connection between language and rhythm plausible. (Patel, 2014).

Patel mentions, "*neuroimaging reveals that pure beat perception (even in the absence of overt movement) engages mid-to-dorsal premotor regions and basal ganglia regions…. Which become functionally coupled to auditory regions. It has been theorized that this functional coupling plays a role in our ability to predict the timing of beats, a key feature of beat-based processing More generally, moving in synchronization with a beat requires tight auditory-motor coupling in the service of an auditory model (a mental model of a temporal interval), just as vocal learning requires tight auditory motor-coupling in the service of an auditory model (the sound an animal is trying to imitate*"(Patel, 2014. P.3) Especially the pathway between the auditory and superior parietal cortex is of interest, since it is believed to be more developed in humans than in nonhuman primates, and could "*account for differences between humans and other primate in the ability to synchronize to a beat*"(Patel, 2014.p.3). Studies with several species of parrots show they are able to synchronize to rhythmic patterns, in a "*manner that is predictive, tempo flexible, and cross modal*" (Patel, 2014. P.3). Other work has been done with the calfornia sea lion, which is no vocal learner and is not know to display rhythmic synchronization in the wild, but is able to learn to synchronize to tempo. This could suggest that auditory-motor circuits are retained from a vocal learning ancestor, commonly shared with seals, sea lions and walruses, which are vocal learners. Even if no common ancestors can be named, comparing animal physiology and behavior can produce new information. The concept of *deep homology* tells us similar biological systems can evolve under the same environmental factors and under the influence of underlying genetic constrains. (Patel, 2014)

Summarizing, the vocal learning hypothesis *"entails the idea that the evolution of vocal learning led to more general integration of auditory and motor regions of the brain than just the circuits connecting auditory and motor control centers*"(Patel, 2014. P.3), and thus might be responsible for our beat-based processing abilities, and there is very compelling neurological evidence that this is the case. Interspecies comparison of temporal processing behavior has already shown to be a fruitful way of gaining knowledge of human timing systems, and further work in this field seems highly worthwhile.

2.4: Difference between music and other Stimuli

The hypothesis of this research is that somehow a musical context helps to accurately remember timing intervals. Therefore it is helpful to precisely define what constitutes musical context, and how musical stimuli differ from other signals. Although there are many differences in personal esthetical preferences, there are some objective structural properties that bind musical phenomena, regardless of cultural or personal distinctions.

One of the most fundamental properties of music seems to be rhythmicity. Although musical forms can be found that lack pronounced rhythmic properties, all popular musical genres have strong rhythmic components. In some genres rhythm can even be seem as the property most dominate feature. This is without a doubt very related to the activity of dancing, where rhythm sets the timing for movement, and thus also seems to be deeply connected to the cultural function music has traditionally fulfilled. Music is often used in tribal rituals and still is a motor for bringing people together in a social setting. Rhythm here serves purpose as a means for orchestrating collective movement (and arguably even mood). When ether we have developed our perceptive skills for music as an effect of this social function of music (as argued by for example Pattell, 2014), or music and these social activities arose because of our embodied cognitive preferences for musical signals, in this context does not matter. The fact is that humans currently have an internalized system of cognition with a strong esthetical appreciation of rhythmic components. Next to an appreciation for rhythm, humans also highly efficient in perceiving and recognizing rhythmic patterns.

Rhythm can be defined as the "*systematic patterning of sound in terms of timing, accent, and grouping*"(Pattel, 2008). It thus refers to temporal regularities that can be observed in a signal. Next to temporal patterns in the stimulus signal, music perception relies on a cognitive framework that can be abstracted from these signal regularities, referred to as *meter*. This abstracted temporal pattern is not necessarily present in the stimulus signal, but forms a structure of expectancies for the continuation of the signal. Music often has a playful relation with this mental framework of expectation. For example, in 'four to the flour'-electronic dance music, the third downbeat is often left out or made less present. So, for a stimulus signal to be judged as rhythmical, it does not necessarily have to have temporal regularities, rather a signal should invite the formation of a mental framework that expects temporal regularities. This is an important observation, since it prevents a purely mathematical analysis of rhythm. The notion of meter as a mental framework also solves the debate that often surfaces in arts about which range tempi can be considered musical. For example, famous composer John Cage experimented with an extremely slow tempo in his musical composition Organ/ASLSP (As Slow As Possible). The concept of meter demands sequential onsets must be in near enough proximity to be associated with each other, and far enough to be registered as singular separate elements, in contrast to what would be perceived as a single tone.

Schultz et al. describe the relationship between rhythm and mete in this manner*; " Rhythm is the "systematic patterning of sound in terms of timing, accent, and grouping"(Pattel, 2008). Meter is the cognitive framework that can be abstracted from rhythm. A metrical framework consists of an underlying isochronous (evenly spaced) pulse that periodically aligns with event onsets at the level of pulse and equal grouping of pulses (London, 2004)…. The grouping of pulses depends on the meter that is abstracted and how often events correspond with pulses (lerdahl & Jackendoff, 1981)"*(Schultz et al, 2013. P.362)

In a musical context, thus there is no single simple rhythm, but instead multiple complex temporal regularities are present on different timescales. The meter structure is assigned by grouping onsets with different properties like pitch, or texture (which are in itself temporal patterns) or intensity. The often-mentioned musical property of melody can also be seen as such a group, where a framework of expectation is not only generated on the bases of temporal regularity, but also on the basis of pitch progression.

Rhythm is not only present in music, but in all sorts of natural signals. It has been suggested listening to music brings pleasure since it stimulates and exercises cognitive structures normally used for efficiently processing other environmental temporal patterns. Recognizing temporal patterns and expecting regularities within series of events seems beneficiary to direct behavior over time. Most temporal patterns are non-random, and arise out of an event happening under the influence of general laws of physics. For example, we use the differences in the signals derived from both ears to localize the origin of sounds, and as a result, are able to spatially localize ourselves in relation to our environment. Another example can be recognized in speech patterns. Rhythmic structures help us to efficiently focus on syntactic structures and semiotics. Rhythmic structuring can even entail meaning on it own, as in for example expressing sarcasm.

If a lot of stimuli have rhythm, what then makes music different? First, it can be argued temporal regularities are most pronounced in music, and are maintained for a long duration. Typical musical phrases in general take up more time than for example sentences of speech, and the temporal regularities are stricter, with a simple pattern being most pronounced (the beat). Other natural sounds can also have these prolonged rhythms (f.e. a jackhammer, washing machine), and are not perceived musical as such. On the other hand, in music made by using sampling, these types of sound are being used as musical elements.
A second major difference of music is that it does not hold direct semantics. While temporal patterns in other stimuli are analyzed to deduct information and decide upon behavior, musical stimulus patterns are analyzed for pleasure. It is not said, music does not contain information, but the information present in music is abstract and more dependent on the perceiver and context the perceiver is in (f.e. mood, social setting). Meaning is assigned to music, on the basis of connotations the perceiver might have with certain auditory rhythms and textures. This being said, certain music can have strong agency to be perceived in a certain way. Often the same emotional connotations are assigned to certain musical elements. This way musical elements can be argued to form an abstract

semiotic language that transcends the individual (but can be culturally dependent). If one would need an example, it can be found in appreciation of the art of DJ-ing. More than picking out records to play and blending them together, a DJ-set also tells an emotive story, sometimes formed interactively with the crowd on the dance floor responding to the music, by dancing and other forms of body language. Many scholars have attempted to objectively correspond emotive states to musical elements with varying degrees of success.

Of course there is also music with vocals, which does directly connect meaning to the more abstract musical elements. This way, artists are able to direct meaning assigned to the other elements of the sound. However, vocals in music are not a necessity, and plenty of musical genres don’t make use of words.

Summarizing, we can define musical stimuli as having pronounced temporal structures in the form of rhythms, out of which a mental framework of expectations can be formed, with at least some of these structure being maintained over a longer period of time. Furthermore, musical stimulus signals are distinct because they are being processed for pleasure, instead of being processed with the aim of directly deriving information.

2.5 Music cognition and Memory for temporal patterns

In previous chapters I have discussed systems used for time perception. However, the system we have for musical cognition is more complex. In this chapter I will describe which other system elements are also necessary to make sense of music. A crucial factor of this system is the ability to encode temporal patterns in memory. As Peretz and Zatorre mention in their paper 'Brain organization for Music Processing', our brain structures for music perception should function in such a manner that they "*generate internal representations of any given input, permitting the stimulus to be segregated from its background, analyzed along several dimensions, recognized, and possibly acted upon. Importantly, the nature of the representations, eventually generated by this system need to be relatively abstract, in the sense that they must be insensitive to superficial variations in stimulus features (loudness, reverberation, spectral filtering, etc). In other words, perceptual constancy must be maintained.* "(2005. P.90) As the reader will recall, the hypothesis of this research is that the encoding of music in this manner is highly efficient and allows for (long-time) memory representations closely related to objective temporal properties of the signal. In this chapter, I will try to base this thesis in the fact that research has shown it is plausible humans make use of distinct and specialized systems for music perception and memorization. As well, I will try to discover which factors related to memory are of importance when designing the experiment.

I will describe the elements a system for music perception requires to function. Furthermore, throughout, I will highlight research that argues specialized and dedicated brain structures are used when processing music. As well, evidence will be mentioned that states that musical memory retains absolute features of the temporal structure of musical stimulus signals. This chapter will also mention some features of musical behavior that are relevant to the experiment design.

Auditory memory systems

Normally the way we remember time passed is in the form of a narrative. We store information about events, and the chronological order in which they occurred. This way temporal information is coded using semiotic representations. Events are given temporal meaning in a causal framework. We determine time between events in a comparative fashion, and can make subjective estimations of intervals of time using causal relations and abstraction from external events. It is normal to phrase answers to questions about time intervals in a narrative way, such as 'we were home before the news, so we walked for an hour'. As Teki and Griffiths conclude, "*the brain can hold information about multiple objects in working memory. It is not known, however, whether intervals of time can be stored in memory as distinct items.*"(Teki& Griffiths, 2014. P1.).

The case can be made that auditory memory does hold objective temporal information. Peretz and Zatorre describe that every sounds unfold over time. In order to be recognized, the auditory cognitive system "*must depend to a large degree on mechanisms that allow a stimulus to be maintained on-line to be able to relate one element in a sequence to another that occurs later*" (2005. P.95). This is not a unique property of the auditory perception system, but the cognition of sound is more dependent on memory functions to place momentary stimuli in relation to one another. A single image from the eyes, for example, holds more information about the cohesive spatial structure of the single elements (although this sense is strongly dependent on the stitching of single directed gazes over time, into a whole representation of a scene). A single stimulus as an effect of air pressure impressing the eardrum only gains meaning in relation to other stimuli in temporal proximity. Perception in this manner can be seen as similar to our sense of haptic touch, in which movement is needed to make sense of separate nerve signals. As our ability to cope with blinking show, the visual sense seem adapt to disruptions in the stimulus signal, while for example in the processing of pitches, ""*disruptions in perceptual processing would likely lead to difficulty in maintain a perceptual trace over a length of time"* (Peretz and Zatorre, 2005. P.96).

It is believed that the working memory for pitch is a specialized subsystem within the framework of general working memory (Marin and Perry, 1999; Schulze and Koelsch, 2012). It has been shown, for example, that presenting similar tones interfered more with a tonal working memory task, than presenting words (Deutsch, 1970). This finding does suggest that auditory stimuli are not stored completely absolute, but instead there is some sort of encoding system at work, that can be distorted by perceiving similar tones out of sequence. There are also some indications of overlap between verbal and tonal working memory, for example, in findings that musical training increases verbal working memory performance (Chan et al., 1998). These correlations give weight to the *vocal learning hypothesis*, which I mentioned in the chapter *interspecies comparison*. The working memory for tonal information is often referred to as the *tonal loop,* and seems to allow us to repeat a short sensory phrase in high quality (Schulze and Koelsch, 2012). Although the research in regard to non-phonological working memory has been sparse, it might be presumed other (short) temporal patterns in auditory signals may also be retained within this specialized tonal working memory, or within a similar but distinct working memory.

Memory systems for music as a memory for objective time

In music, as argued in the previous chapter, large temporal structures are part of the phenomena's very being. Therefore, memory structures are crucial to be able to perceive music. Following Peretz and Zatorre, we need at least short temporal patterns absolutely encoded in memory to recognize sounds. The open question of musical memory then becomes when ether we also objectively encode larger temporal structures present in music, or that we have means of encoding larger temporal structures using smaller building blocks that store a representation of absolute timing. A musical piece is not perceived as a whole, but like all sound, is perceived over time. This shows that in any case, we can perceive and encode the smaller temporal patterns separately (musical phrases). It is therefore more plausible the repeated structures of temporal regularity present in music allow us to use the aforementioned narrative and semiotic memory structures to stitch smaller parts of absolute timing information into larger temporal structures. In this manner, the structure of music could present us with a *segmentation strategy*, like the explicit counting of seconds, with the objective temporal information from auditory (working) memory acting as segments, and with a structure that can be saved in a non-semiotic memory representation using highly specialized brain structures (different from counting). Also speaking for this model is the fact that, if objective temporal coding of large musical structures occurred, and the complex repeating structures of smaller structures were not to blame, another stimulus property had to be found to explain why temporal information in music is processed differently form other stimuli, in the sense that is less prone to be summed in efficient meaning. Whatever the case, music might give use means to encode long intervals in a way that retains information about absolute, objective time.

Memory encoding of music

It seems an important distinction between musical memory and most other types of memory representation systems (including the auditory) is that musical perception does not directly encode meaning. As Peretz and Zatorre put it; "*The musical memory is a perceptual representation system that is conceived as representing information about the form and structure of events, and not the meaning or other associative properties. Music is by essence perceptually driven.*"(Peretz and Zatorre, 2005. P.96) Semiotic memory can be seen as formed by neural connections between abstractions of sensory concepts (which are in turn in itself a web of neural connections), which are thus given meaning in a framework of association. The best analogy for such a system of making sense of meaning is probably language. With language, we can talk about abstract concepts, and describe all abstract concepts using different, related concept descriptions. Using descriptions we always both simplify and generalize a concept, leaving unique properties of an occurrence out, and as well connecting a concept to more meaning that can be perceive from a single, distinct sensory event. These generalizations thus both contain more, and less information about a unique concept. This allows for efficiency in processing meaning, but renders the quality of perception lower, in the sense that the representation is less related to an objective sensory event.

In musical processing the emphasis lies not on the semiotic concepts, but on the (temporal) structure in which sensory information is encountered. On one hand, we thus seem to have less of the luxury of generalization, since it would cut short the experience of time that is enjoyable about music, which could make one speculate the quality of the sensory representations needs to be higher to be able to capture the being of music. On the other hand, encoding still occurs, and contradictory, is essential to experience the regularities of musical patterns. This points toward musical memory being a complex mix of efficient encodings of regularities in time, and high quality objective representations of temporal patterns. As Graton et al. mention, "*both sensory as well as more abstract features may be encoded in stored musical representations*" (2016. P.2)

Peretz and Zatorre provide a useful analysis of musical memory representation, that mentions both abstract encoding of patterns, as well as retaining memory representations close to the objective properties of sound:

> *"Perceptual memories of familiar tunes must be relatively abstract in order to allow recognition despite transposition to a different register (Dowling & Fujitani, 1971), change in instrumentation (Radvansky et al., 1995), and change in tempo (Warren et al., 1991). The stored representation can nonetheless preserve some surface features, such as absolute pitch and precise tempo (Halpern 1988, 1989; Levitin 1994; Levitin & Cook 1996). This duality is congruent with our intuitions as to the role of memory in music listening. On the on hand, most listeners will not remember ever detail of a musical segment but instead will follow the piece by a process of abstraction an organization, remembering its "gist: (Dowling & Harwood 1986, Large et al. 1995). Om the other hand, appreciation of interpretation requires the consideration of surface characteristics that are unique to a particular rendition (Raffman 1993). Thus, both surface and structural features may be contained in the stored representations and fit with the role and definition of the perceptual representation systems that are posited in other perceptual domains. "(*Peretz and Zatorre, 2005. P.96)

The surface features mentioned in this description, might be the way in which we are able to store short representations of objective time in memory. The structural features of music could present us with a way of stringing together these sensory encodings that preserve objective timing, into longer intervals. The question then arises in which way music is processed, and how relations in time are encoded, and thus generalized.

Specialized brain structures for music processing

As concluded before, the key to the cognition of music is to perceive and recognize temporal patterns, and make mental abstractions of these patterns to form a framework for the expectancy of regularity within the ongoing signal, and throughout this process encode and retrieve representations of temporal patterns from memory. In this subpart, I will mention research that sheds light on how these cognitive tasks are distributed in the brain, and thus how musical processing is performed. This evidence also strongly suggests musical structures are processed differently from other stimuli, and perceiving temporal patterns in music may benefit from the involvement of highly specialized brain substructures.

As mentioned by Peretz and Zatorre, "*two types of time relations are fundamental to the temporal organization, or "rhythm" of musical sequences: the segmentation of an ongoing sequence into temporal groups of events based on their duration values, and the extraction of an underlying temporal regularity or beat (Fraisse 1982). Beat perception leads to the perception of a metrical organization corresponding to periodic alternation between strong and weak beats (the strong* *beats generally correspond to the spontaneous tapping of the foot)."*(Peretz & Zatorre, 2005. P.94) Grouping is here mentioned to be performed on discrimination of onsets based on duration values and 'strength' of a beat, however, I believe more complex auditory properties of a signal can used if they contribute to an expected temporal regularity (f.e. texture or pitch).

There has been some neurological research on which brain systems are responsible for subdividing onsets into groups, and the analysis of regularity. Findings show different, specialized substructures of the brain perform these two actions. For example, Ibbotson and Morton (1981) shown that subjects are more accurate tapping rhythms with their right hand, and more accurate following the underlying beat with their left hand. This finding suggests that the right hemisphere is responsible for processing meter, and grouping of onsets happens in the left hemisphere of the brain (Ibbotson and Morton, 1981). This speculation is supported by research done with subjects that suffer from brain damage in the right temporal auditory cortex, who are unable to generate a steady pulse (Fries and Swihart, 1990; Wilson et al., 2002). These two patients were still able to discriminate and reproduce irregular intervals. Researchers have also shown, the perceptual property of assigning meter can be impaired as a result of brain damage. Patients who had their left or right temporal lobe removed were able to discriminate rhythmic patterns in a normal fashion, but fail to assign meter after a right –sided lesion of the anterior part of the superior temporal gyrus (Liegeous-Chauval et al. 1998, Peretz, 1990).
Further evidence distinct brain structures are responsible for the segmentation of onsets and dealing with the regularity of a signal, is provided by Sakai et al. (1999). Using neuroimaging they were able to show metrical rhythms may be processing differently from nonmetric rhythmic sequences in the brain. All this evidence is consistent with the view that grouping of onsets and the interiorisation of regularity are separate cognitive tasks. (Peretz and Zatorre, 2005)

Interestingly, there is also evidence for a strong relation between mental representations of rhythm and motor components of the brain. This show in parallels in performance between production and perceptual tasks, as well as from data derived from neuroimaging and studies with patients suffering from brain lesions. Perhaps unsurprisingly, similarly as seen in neural research on time perception, in music processing the cerebellum and/or basal ganglia are suggested to play the part of a central mechanism controlling motor and perceptual timing (Janata and Grafton, 2003; Ivry and Keel, 1989).

Working memory for music

There can be found some evidence for the existence of a specialized tonal working memory. As mentioned before, this area of working memory has not been the topic of much research, but there are reasons to believe it is similar or shared characteristics to the other forms of working memory for auditory signals (for example the phonological loop), or other form forms of working memory (such as the visuospatial sketchpad). In such a specialized system, a high quality representation is maintained over a short period of time, and this system benefits from active 'rehearsing', and is often said to rely on engaging motor-systems. (Schulze and Koelsch, 2012; Peretz and Zatorre, 2005; Marin and Perry, 1999)

Sequence memory

The way in which short highly objective, high quality memory representations of shorter temporal patterns (the tonal loop?) and larger abstract encoded structures are linked might be related to the concept of *sequential memory*. This type of memory processing can be seen as related to the aforementioned narrative semiotic way of encoding time. Namely, in this type of processing, the chronologic order of stimuli is the motor for the organization of memory. This type of cognition is not unique for the processing of music, but also is observed in cognition related to for example speech or movement.

The amount of information that can be stored in working memory is limited, but by dividing the information in distinct parts, with stronger associations between items in one part than between the different part, performance can be increased. "*This process is assumed to be supported by the episodic buffer enabling features from different sources to be bound into chunks and new information to be integrated into an existing context stored in LTM*" (Schulze and Koelsch,2012)

Entrainment

A lot of scholars studied the phenomena of entrainment, a subject I briefly touched upon in the description of oscillator models of time perception. In short, it is the dynamic synchronization of the internal clock frequencies with external environmental temporal patterns. These internal clock frequencies can be maintained after the stimulus signal is stopped. This way a tempo can be maintained and perhaps leads to greater accuracy in interval timing. Entrainment, however, is difficult to directly bring in relation to recreating rhythm from long-term memory, which is the primary topic of this paper. It is very likely, however, the phenomenon of entrainment plays a part in the encoding of stimuli in memory representations.

The role of learning and skill in music perception

Learning

When talking about the memorization of music, another pattern in our behavior becomes important. As mentioned before, different from other types of stimuli, the primary goals of listening to music is gaining pleasure. As a result, we often repeatedly listen to certain musical pieces. Although first limited by the consistency of musical performers, technology in audio recording and playback allows us to listen to the exact same performances over and over. Nothing permits us to do this with other stimuli patterns, but in practice this repeatedly exposing ourselves to the exact same temporal stimulus patterns is rather unique for the phenomena of music. Especially for auditory stimuli, this behavior is not been observed (with the exception of the short notifying sounds used in electronic or digital information systems). This behavior in itself might account for great accuracy in the recollection of absolute features of the signal, since unsurprisingly "*Research in the field of memory has established…. that repetition is essential in the development of memory*" (Blum, 2013.p.125).

Moreover, "*music with significant repetition and hierarchical structure is easier to remember than music lacking these characteristics*"(Snyder, 2000) This shows an interesting balance needed to remember a music piece; repetitive elements, and elements of disruption, also needed to make something distinguishable, noticeable and worth remembering.

The element of repetition can be crucial in the experiment design. If learning is expected to be one of the causes for greater accuracy in memorization of interval time, participant should be repeatedly exposed to the musical context used in the experiment. At the same time, if the research tries to find other explanations, the learning factor should be used as an independent variable, or the musical context should be compared with different repeated stimuli (for example a speech).
As well, musical elements too simplified, might prevent engagement brought about by the constant recreation of a mental framework of expectation, as happens in 'natural' musical phenomena.

Skill

Another factor that should be considered is the skill of the participant in the processing of music in general. A skilled musician might be better adept to recognize and memorize temporal patterns. There is strong neuroimaging evidence that states musicians and non-musicians active different brain substructures when using tonal working memory. Musicians seem to more strongly activate neural networks (Braca's area, left premotor cortex, left insular cortex, (pre-)SMA, cingulate gyrus and left IPL), nonmusicians activate when undertaking verbal tasks (Schulze and Koelsch,2012). It has been suggested musicians have trained to form a strong relations between tonal information and sensorimotor processes, and involve these sensorimotor processes in the encoding of representations in (working) memory. This is similar to the way in which we involve motor processes for speech in retaining verbal working memory, mapping the perceived speech signals into articulatory representations. Musical training thus is an important independent factor that should be correlated for when analyzing research results.

2.6: Evidence of the memory of music being partly absolute

The thesis of this research states that musical memory is partly absolute, in the sense it is able to form long-term representations closely related to the objective temporal properties of sensory events, and thus musical memory retains parts of the sensory experience in high quality. This would make it different from other forms of memory, in which we have trouble retaining an objective view on passed time, and instead rely mostly on the retrieval of subjective meaning. In the following part, I will present some evidence objective temporal properties are encoded in long-term memory.

2.6.1: Lack of temporal binding

An important piece of evidence for musical memory storing these temporal structures in a more absolute manner is the seeming lack of a *temporal binding effect* in rhythmic contexts (Repp, 2011). Although this question needs further investigation, these findings suggest a musical context has agency for letting subjects process sensory stimuli in a more temporal objective manner. Temporal binding is a subjective psychological phenomenon in which the time between the cause and effect in a causal relation is not perceived by an observant. Bruno H. Repp defines this effect as "*a subjective contraction of time that elapses between an action and a delayed sensory consequence of it*" (Repp, 2011. P.491).

Actions and their perceptual consequences normally are strongly connected, and almost every action sets in motion perceptual feedback, which often, in turn, is used to take follow up actions. Sometimes, cause and effect are distal, and it takes cognitive effort to connect the events and recognize relations of causality. However, humans are skilled at causal binding and often over-impose causality without proof. When we click with the mouse of a computer, it might take a few seconds for a window to open. Still, we have no trouble recognizing the causal link between both events. The hypothesis of temporal binding states that this causal binding influences the perception of time. This manner of cognition would allow for efficient memory encoding of causality, and thus making sense of our environment. It also shows the way normal time is encoded in memory, by placing events in chronological order, in a narrative on the bases of cues of causality. Temporal binding has been demonstrated in, for example, tapping tasks. In these experiments subjects were asked to press a key, which triggered a delayed tone, and participants were asked to judge the timing relative to a visual reference. Subjects incorrectly reported the tone to occur earlier in reference to a visual cue (rotating clock hand), when caused by a key press, compared to a control condition in which the tone happened without a key press. These sorts of findings "*imply that the temporal interval between action and its consequence is shortened subjectively*." (Repp, 2011. P.492)

Bruno H. Repp performed an experiment with the action consequence embedded in a rhythmic sequence. Repp reports that no temporal binding effect occurs, and within the rhythmic context subjects judge intervals closer to the objective interval time. Repp speculates "*an auditory rhythm may provide a 'ruler' against which the temporal position of a test tone can be judged accurately*" and this way "*internal rhythmic references may have enabled them to overcome TBc* (the temporal binding effect)". (Repp, 2011)

2.6.2: Absolute pitch and absolute tempo

More evidence of the 'absoluteness' of musical information stored in the brain can be found in phenomena of *absolute pitch* and *absolute tempo*.

Absolute pitch is an individual skill that is relatively rare (0,01% of the population (Graton et al, 2005. P.4)). Subjects that have the ability for absolute pitch can perfectly identify and recreate a pitch frequency from memory without the need of a reference tone. Graton et al. define absolute pitch as "*the ability to recall pitch from long-term memory either to identify the pitch or chroma (pitch class) of a tone present in isolation, or to produce a specified pitch without an external reference*"(2005. P.4). This ability does not presents itself uniformly, and multiple variations of this form of cognition can be observed. Some subjects appear to be able to identify objective pitch, but perform normally in production tasks, or the other way around, indicating cognition related to pitch engages multiple distinct brain subsystems. There are some indications absolute pitch benefits from training, and some form of AP can be attained from practice. Interestingly in this regard, is the fact that absolute pitch processing occurs more often in populations that use tonal languages. Mostly, however, AP seems to be a genetic ability that on is born with. In relation to the present research AP is of interest because the "*phenomenon of AP provides strong evidence that at least some of us are capable of processing musically relevant representations without an external reference*" (Graton et al., 2005. P.4).

Absolute tempo

More evidence of this assumption can be found in what is called *absolute tempo*. Graton et al. describe this phenomenon as "*the ability to identify and reproduce tempo in the absence of rhythmic or melodic frames of reference*" (Gratton et al., 2016. P.1). Both the processing of pitch and tempo relate to the identification and production of frequencies, but it is generally accepted, that the processing of the higher frequencies involved in pitch, benefits from different forms of automation, and the cognition of tempo takes more cognitive effort. Unlike absolute pitch, absolute tempo seems to be an ability commonly found in the general population (for example, Graton et al. (2005) report more than half of their subjects perform above chance in tempo reproduction). The phenomenon of absolute tempo is crucial for the present research, since it can be seen as the underlying basis of interval estimation in a musical context. If an auditory rhythm presents us with a 'ruler' against which temporal positions can be judged (Repp, 2011), the ability to process tempo sets the accuracy of this reference.

As pointed out before, the ability of people to recognize a song, even when the tempo is altered, argues for a relative encoding of tempo information in memory. Such a relative encoding represents the structural relations between the components of a stimulus array. This way the pattern recognition involved in recognizing a song can be performed. Single attributes of specific stimuli (like pitch) have less means of being retained within a structural pattern, and must therefore rely on more absolute memory encoding. However, when individuals are asked to reproduce a song, they tend to reproduce both the tempo and pitch accurately (Levitin and Cook, 1996). This points towards musical tempi also being encoded in an absolute manner in long-term memory. This makes logical sense since tempo cannot be expressed fully in encoding just the structural relations between musical elements, and instead one could argue, a priori "*tempo is necessary to achieve a sense of connectedness between successive musical events*" (Gratton et al., 2016. P.2), while perceiving and encoding the structures within a musical piece. As well, before reproducing a song from memory, a musician needs to have a representation of the tempo, and more so, must maintain this tempo representation even when his performance deviates from this tempo for expressive purposes, or due to errors in muscle movement.

Levitin and Cook performed an experiment, in which participant were asked to name and reproduce their favorite songs (1996). Their performance was recorded, and the tempo was compared to the original recordings (while they checked if participant referred to the same canonical version of the song). They reported that 72% of the reproductions were within +/- 8% of the original tempo. This held true even when participants reported no musical training. They mostly found overestimation errors, which they suggested to be related to performance stress, which is known to induce speeding. Pauws performed a similar experiment in which he asked to reproduce familiar *Beatles* songs after listening to a CD (2003). Two thirds of the subjects came reasonably close to the recording, and again no difference was found in regard to musical training.

Lapidaki designed an experiment in which the consistency of their subjective tempo judgments was tested (2006). Subjects were invited to listen to six unfamiliar musical examples and asked when ether playback should be faster or slower to achieve a tempo that felt right for the musical piece. A small number of participants were remarkably consistent in these judgments across multiple trials, and relatively unaffected by factors as fatigue, mood or time of day. Collier and Collier took another approach and studied jazz recordings (1994). They observed musicians were consistent over multiple recordings without the use of a metronome. Fine and Bull asked subjects to listen to three tempi (35, 110 and 185 bpm), and reproduce the tempi from memory using handclaps (2009). They report the slower and faster tempi were better recalled that the in between tempo.

Graton et al. asked participants to perform simplified identification and production tasks on multiple metronome sequences without musical cues (2016). The tempi were chosen to form a logarithmical scale of seven semitempi, and subjects were asked to judge which of the tempi they heard, both by means of labeling (1-7) as well as reproducing the tempo by tapping on the table. Subjects were assigned into groups on the basis of their musical training. They observed that 48.6% of responses in identification and 22% in production fell within +/-1 semitempo from target and 87.6% of responses in identification and 47.1% in production fell within +/- 2 semitempi (12%) from target. They report 5/30 participants (three musicians and two non-musicians) performed above chance in both identification and production, and 9/30 participants (seven musicians and two non-musicians) performed above chance in identification, but not in production, and 2 participants (non-musicians) performed above chance only in the production task. More than half (53%) of participants were able to perform above chance in at least one of the tasks. The majority of these were musicians. These findings suggest that at least "*some individuals have the ability to retrieve the temporal rate of an acoustic event without a reference*", absolute tempo is fairly common, and might be present regardless of lack of musical training (Graton et al.,2005. P.16).

Summarizing, we can say that, although research is relatively sparse, there is some evidence some individuals have the ability to preserve absolute representations of tempo in (long-term) memory, and that this is a fairly common ability when compared to absolute pitch. In general human cognition, thus, is able encode objective temporal information of musical events in long-term memory, but performance varies heavily across individuals. Absolute features of memory may benefit from training, but differences are foremost explained by genotype.

2.7: Conclusions on theoretical framework

Looking at the gathered literature, some conclusion about perception of objective time can be proposed. It is not exactly clear how we perceive time, but it seems like we perceive timing based on multiple interacting systems instead of one single system, and there seems to be evidence that different timing tasks trigger particular systems, with different characteristics, to different extends. This leaves room for my hypothesis that timing in a musical context can involve different, more accurate timing mechanisms.

Another observation is that there is no evidence that time can be memorized as a separate entity, but instead needs a medium or structure to gain meaning and to be stored in memory. This type of cognition seems quite logical when regarding the metaphysical being of time, discussed in the chapter the ontology of time. Time can best be regarded as an effect of the rate of processes taking place in space, so it makes sense for memory to encode time as an effect as well.

Our subjective memory of time passed, thus, is always connected to a structure, which is used to make deductions of objective timing. Examples of such structures are narratives, causal relations, natural cycli, rhythms, and sentences. Such a structure alone does not hold information about time, but instead saves information about the chronological order of events. The concept of sequence memory seems to best describing these structures in memory, with stronger associations between events in close proximity to each other. This type of abstract encoding of information is efficient, since no high quality representation of sensory stimuli need to be retained, and such a structure is flexible and thus able to deal with changes of parameters (for example recognizing a song in different tempo).

This sequential structure alone cannot by itself capture objective timing information. For that we need representations in memory that can be meaningfully connected to objective time passed. In the reviewed literature, several systems for encoding of objective timing have been proposed (such as for example motor feedback timing). One thing most models share, is that representations that store information about time itself are of very limited duration, and for timing longer durations we rely on the fore mentioned more abstract structures. The concept of the specious present best describes this phenomena, and there is compelling evidence to conclude that, the only sense of objective time we have, is constructed by summing segments that can be perceived in the duration of the this so-called specious present (approximately only a few seconds). These representations are high quality and retain information closely related to the sensory experience instead of abstract encoding.

In short we can say, that it apparently takes a lot of cognitive effort to store representations of sensory stimuli in such a high quality that they entail indirect temporal meaning, and the mind tries to minimize this effort by using rather aggressive methods to sum and encode temporal information efficiently (as is seen in the effect of temporal binding). I thus propose a model for perceiving and storing time, which has two elements; short, detailed and high quality segments of sensory representations, which indirectly store temporal information, and larger, abstract, sequential structures that meaningfully connect segments in relation to each other. For example, the former can be made up of an encoding of sound in the working memory of the 'phonological loop', and the latter can be the syntactic structure of a sentence within the causal relation of a narrative. Or the segment can consist of the encoding of a sound texture or pitch in a specialized working memory, within the structure of a bar within the chorus of a song. Another example can be the distinct muscle feedback from the Biceps Branchi overlapping the feedback from the Tibia, in the larger regular pattern occurring when running.

These theories of mostly unconscious timing mechanisms give merit to the use of explicit segmentation strategies. In such an active strategy for objectively timing an interval, a short sensory segment is chosen that holds information about objective time, and it is put in a more abstracted structure that connects the segments and can be memorized and retrieved with less use of cognitive resources.

3: Experiment design

The following section will describe the design of the experiment that is conducted to interpretatively test the model proposed in the last section, as well as the hypothesis that musical memory of objective temporal information is more accurate. The goal of this experiment is to explore when ether different explicitly provoked segmentation strategies involve different types of cognition and memory encoding. The hypothesis I had, that timing cognition in a musical context is performed differently, and the resulting representation in memory is closer to absolute timing, seems to have some grounding in previous researches. If this were the case, I would argue this would lead to performance differences in reproducing timing intervals. To test if time is indeed processed differently when evoking a musical context, an experiment is set up that compares subject's accuracy in reproducing timing intervals presented in three different implicit contexts.

In this experiment I choose to focus on active explicit segmentation strategies, rather than implicit subconscious segmentation mechanisms. This is done for a few reasons. In first, on the basis of research on absolute tempo, we expect large differences in individual performance. Research suggests a majority of people retains a good sense of tempo, while a minority performs much more poorly. On the basis of this expectation, an in-subject designs seems better adapt to compare different types of cognition of time, since it prevents differences being contributed to individual skills. This means we want to test participant for all conditions, which means multiple interval timing tests. With multiple tests, it is hard to implicitly invite people to use a certain type of segmentation. We could embed the first temporal cues in a sequence we suspect triggers a certain cognition, but it would be extremely hard to do it a second time without the subject expecting an interval test. I expect that a different type of cognition (and different segmentation systems) is used when doing a certain timing task. When consciously timing an interval, a strategy always seems to be actively chosen. For example, when being asked to time an interval, most people use the strategy of counting. In a second test using implicit design, the subject would suspect an interval test would follow, and they would actively select a type of segmentation strategy. This might prevent the type of timing task from triggering a certain type of segmentation I want to investigate. For example, participants might use the counting strategy in a musical context. In such a design it would be hard to contribute differences to a certain context.

Instead, I choose to invite the use of certain segmentation as explicitly as possible. This entails actively instructing them to use a strategy. As well, participants are asked to perform segmentation out loud. This way I have means of checking which cognitive behavior is undertaken, and with this explicit activation of a certain strategy I hope preventing different strategies from being performed subconsciously.

Since the most natural strategy of focusing attention on the passing of time, for me personally, is the segmentation strategy of counting, this strategy is used as base comparator. An initial test without explicit instruction is also performed to test what strategies are used, and if counting is indeed the most popular. Next to counting two other strategies have been devised, one being based on music, and one on language. Language is chosen because it seems like an interesting comparator, since language is highly structured but other than the other strategies, the structure is based on semantics and meaning rather than temporal regularity. In the strategy of counting and the musical strategy, a rhythm forms a regular temporal scale, which can be used for referencing the representations formed from shorter elements (like counts and pitches), which are thought to be encoded in higher quality and thus contain information about timing. In the context of language, the previously discussed *phonal loop* might contain temporal information (which is suspected to store indirect timing information by means of articulatory motor feedback), and the larger, more abstract sequential structure is not formed by means of temporal regularity, but on the basis of semantics and narrative meaning.

Measuring performance differences between these three strategies, can tell us two things. If timing performance differs, it is likely timing cognition is performed differently on the basis of context. And secondly, which segmentation system encodes objective time in memory in the highest quality, thus testing the hypothesis that musical memory is better adapt for storing temporal information.

The idea is to keep the implementation of the strategies as similar as possible, and only change the segments and structures used in cognition of objective time. Looking at the counting strategy it can be described as follows;
An external cue starts the process, after which an internal rhythm is referenced to segment portions of time. Each segment that has passed advances the count. The structure that is used is the order of the decimal system. Only the sum is stored in memory, and for reproduction of the interval we reverse the process, referencing the time of each count from an internal rhythm until we reached the number we remembered.

To allow the strategies that make use of music and language as similar as possible, I made the choice to also have the systems used completely internalized. An alternative would be, providing a context during the learning of the interval of time, and allowing the same context during reproduction of the interval. This would mean, for example, embedding the interval cues in a musical sequence, and after a period playing the same sequence asking subject to give cues at the same moment they heard them previously. Comparing such a passive strategy to the active strategy of counting did not seem fair, with an advantage being present for the passive method. This would have meant it was fairer to provide a reference pulse for the counting strategy as well. The primary topic of this paper is how time is stored in (musical) memory, and such an embedding approach would investigate memorizing of intervals within a context, instead of storing temporal information in a different format. As well, the outcome of such a research would be less useful in every day life. If alternative strategies indeed are more accurate, they can be used as an alternative of the regular counting strategy, being used to estimate intervals in everyday life.

So instead, the choice is made to provide subjects the opportunity to first familiarize themselves with a musical sequence or small text, asking them to reproduce this sequence or text from memory during the presentation of the interval of time that has to be remembered, and perform the reproduction while reciting the sequence or text from memory. This way they do not directly try to store the temporal information of the interval in an abstract way, but instead are invited to remember a context that indirectly holds temporal information.

The experiment is performed with the help of a custom computer program. The program handles the instruction, is used to teach the participants the text and the musical piece, and is used to record the response. The choice is made to test the accuracy of the memory by reproducing the interval, instead of for example a comparative method. A forced choice design would have meant exposing the participant to extra intervals of time, complicating the memory they had of the original interval. The response is recorded by using the time participants leave in between two button presses.

The order of the three test conditions (further referred to as counting, language and music) is randomized, to be able to reject the influence of the order in which the conditions occur. The test without instruction is taken first, since it used to ask participant which natural strategy they use.

<u>Memory component</u>
One of the variables in accurately estimating time is memory degradation. It seems logical that the memory of an interval of time is better reproduced after a short period, compared to being reproduced after a longer period. Different types of encoding of temporal information, will very probably lead to different speeds of degradation, and so the rate of degradations seems telling if indeed different systems are responsible for reproduction performance. This research started with the observation that it seems remarkable how music is stored in long-term memory, and thus I suspect reproduction of intervals using musical segmentation strategies to remain more accurate longer after encountering the timing interval.

I choose to test this by performing two reproduction tests for each condition; one immediately after exposing the subject to the interval to be timed, and once again a few minutes. During this waiting period, subjects were asked to perform a simple distracting task using a different modality. For this I choose a task that involved coloring in a drawing of a bird for three minutes. This way I hope to be able to say something about the persistence of the encoding of temporal information in memory for the presumed different systems.

<u>Selection of materials</u>
Ideally, using a segmentation strategy based on text or music, the subject has to have memorized the material as extensively as possible. In this experiment I only have one moment of contact with the subjects, thus I did not have the

opportunity to allow participants to familiarize themselves with the material before the experiment. This limited my choice in materials, since they had to be simple to be able to learn in a small amount of time.

In the chapter 'what makes musical stimuli different', I arrived at the definition of music as a prolonged pattern of stimuli on the basis of which temporal regularity is expected, and which is processed for pleasure instead of analyzed for meaning. I thus wanted a musical piece that had a steady tempo, a melody that can be hummed out loud to check if the strategy was being used, and the piece should contain no lyrics. Also, music often has multiple rhythms on different timescales that coincide, forming more complex patterns. These patterns together form a higher resolution reference than just one rhythm, which could be beneficial for timing accuracy.

I thus picked a 'natural' musical piece, instead of creating a simplified abstraction of these properties. Taking a popular piece of music ensures it is regarded as music. Furthermore, it would help subjects internalizing the song, if they are already familiar with it. It was hard to find a song that checked all of these boxes; most popular music has lyrics, and within the genres that do not, like classical music or electronic music, pieces are often performed at varying tempi. It would distort result if during the interval representation they referenced the tempo presented, but during reproduction they remembered a performance in a different tempo. In the end, the piece 'popcorn song' by Hot Butter was chosen (1972). Of this song only one version was popular (although multiple versions do exist), and most people referenced said they recognized he canonical version of the song. Furthermore, it is performed with electronic instruments, ensuring a steady tempo, and it has multiple rhythms, with a dominant melodic voice that can be easily hummed. As well, it is often referred to as being a so-called ear worm, so it should be remembered rather easily. A fragment of 16 bars was used.

My considerations for selecting a text were similar. I wanted a text that was famous, and thus previously familiar and regarded as representative for natural texts. During preliminary testing, the speech 'I have a dream' by Martin Luther King was used. It was selected because it was famous, and had a strict structure with reoccurring elements. However, it proved difficult for subjects to familiarize themselves with the text, since it uses a-typical semantics, and complex language. This also made it difficult to recite the text without making mistakes. Mistakes caused people to correct themselves, distorting the timing performance. As well, it lacked a clear narrative structure based on causality that can be used as a reference while retrieving the sequential and syntactical order. So for the actual experiment, instead, the simple rhyme 'Humpty Dumpty' was used. It is supposed rather famous and can be easily remembered. As well, the rhyme has a narrative based on causality, as well as rhyming words, which form internal relations, which can be used as a reference for the sequential order. Since it is only four sentences long, participant are asked to repeat it until the time interval is reached. This is a compromise, since counting the amount of times the rhyme is repeated is an extra task and uses the same strategy as the counting test condition. However, this choice is made since learning a longer text during the experiment was hard for participants, and during the short interval of time that needed to be reproduced, the amount of repetitions is very limited (approximately 2-3 times depending on speed of recital) and keeping the count in memory should not put a lot of strain on cognitive resources.

Length of the interval
The interval that has to be estimated is 20 seconds for each one of the conditions. I choose this duration since it is of a size that according to the literature it benefits from using a segmentation strategy, but is short enough to segment it using a short musical segment or text that can be learned during the experiment. Keeping the interval the same for all condition makes it possible to directly compare results, and it is not expected performance will enhance by timing the same interval multiple times using a different method.

Questionnaires
After each of the test the participants are asked to fill in a questionnaire. After each test, subjects are asked how confident they felt with the response they entered, and after the tests with a instructed strategy, how difficult they found it to use the strategy as instructed. After the initial test without explicit instruction on a strategy, they are asked if they made use of a strategy, and if they can describe it. After the test based on the textual strategy, subjects were asked if they knew the rhyme and if they could write down the text to see if they can reproduce it correctly. If they consistently use wrong wording during the interval presentation and reproduction, the segmentation strategy shouldn't have to suffer, but if they remembered little of the text, this is unlikely and I should discard the results. After the musical segmentation strategy test, subjects are asked if the song was familiar. When it was, it is more likely they were able to hum it consistently.

After completing all of the interval timing tasks, subjects are asked which strategy they felt was the hardest to use, and which one was the easiest to use. As well, participants asked to judge their skills in the English language. This answer can be correlated to performance in the language test. Participants are also asked if they received musical training, and if so for how long. This answer can be correlated to performance in the musical test condition.

Procedure
The computer program was coded in C++ using the Openframeworks-Libaries. The program was run on a Macbook pro 2011 (dual core i7, 8gb of ram). Participants were first instructed on the test procedure by the examiner. They were told the aim of the test was on interval timing, and that multiple test would follow, each with it's own set of instruction. It was explained they would hear an interval, marked by two distinct sounds, and at a later moment they would be asked to reproduce the interval, by means of pressing the <spacebar> two times while leaving the time they remembered in between both presses, like if they were operating a stopwatch.
As well, it was explained the program would ask them to fill in some questions after each test that they could fill in on paper. They were given five booklets, numbered 1 to 5, and told the program would instruct them which booklet belonged to which test, and tests would not necessarily be in order.

After these instructions subjects were sat down behind the laptop, and put on a headphone (a Sennheiser hd-25), and asked to dial in the volume to a level they felt comfortable with. Then the program was started. In attachment #, all screens of the program are displayed.

The program started by again explaining the test procedure. This was done to assure to operation was completely clear, and all subjects received the exact same minimum of instructions. The initial instruction by the examiner was added primarily because the instructions on screen alone could be experienced as intimidating, and the instruction was an opportunity to make sure the participants felt comfortable in the test setting. Next to making sure the procedure was clear, the instruction contained within the program allowed participants to familiarize themselves with the controls of the program, such as pressing <return> to advance to the next screen. As well, during this introduction participant could practice with interval reproduction. Between both presses a timer was shown to make clear the timer was started. After the instructions, subjects were asked if everything was clear, and given the opportunity to repeat the instructional part, or ask the examiner for further explanation. If everything was clear, the initial test started.

In total four tests would be taken. For the tests, the procedure was as follows;

- Additional instructions
- (Only during the musical and semantics test conditions) Learning the segmentation material
- Interval presentation
- First reproduction test
- Coloring task (4 minutes)
- Second reproduction test
- Filling in the questionnaire belonging to the test

The program always presented the initial test without instruction first, and the order of the three remaining test (with instruction) was randomized. After all test are completed, subjects are asked to fill in the last questionnaire. In total the experiment took the participant between the 25 and 30 minutes. 14 Participants have been tested using this procedure. The tests were taken in a quite room, with only the examiner being present. An audio recording was made of the test, to check if the parts of the test that were out loud, were correctly performed.

4: Results

In this part, the results of the experiment are reported. After describing the general preparation and distribution of the dataset, the data that was recorded will be investigated along several separate questions listed below;

- **Is it common to use a conscious segmentation strategy when being asked to time an interval? Is the counting segmentation strategy the most common?**
- **Was the use of a strategy beneficial during the initial test without instruction?**
- **Are there differences in performance measured for the four conditions?**
- **Does using a musical strategy lead to the most accurate reproduction of the interval?**
- **Are there differences between the conditions in the way the interval memory decays during the distractor task?**
- **Do musicians perform better in overall timing, or in the musical test specifically?**
- **Are there individuals who perform better or worse than the majority of subjects? And if so, can different trends be observed for the different groups?**
- **Which strategy was reported to be the easiest to perform, and which one the hardest?**

Preparation of the dataset

During the tests, one person reported making an error pressing the button. The result of this test is excluded from the dataset.

During each of the test, the aim was to reproduce a 20 second interval. Since the primary interest of this research is on accuracy, for most hypotheses it made no difference whether subjects reproduced a shorter or longer interval, but only how much their response deviated from 20 seconds. This ratio variable was computed for each of the eight tests, and these variables are used for further analysis. An attempt has been made to see if certain test had an agency for triggering late or early responses in the original reproduction variables, but no obvious trends have been observed in the data.

Distribution of dependent variables

The distribution of the dependent variables in the form of the deviation variables was investigated using histograms. No clear centered distribution was found in the responses for seven of eight tests. The Kolmogorov-Smirnov test was performed, and supported this observation. In seven of the tests the responses were significantly different from a pattern of normal distribution. One variable seemed to follow the pattern of normal distribution, both visually in the histogram as well as objectively in the Kolmogorov-Smirov statistical test (p= 0,200). This was in the second reproduction of the Musical strategy test. Since no such pattern was seen in the first reproduction test, which should be related, this result is regarded as a coincidence, and all data is treated as being non-parametric.

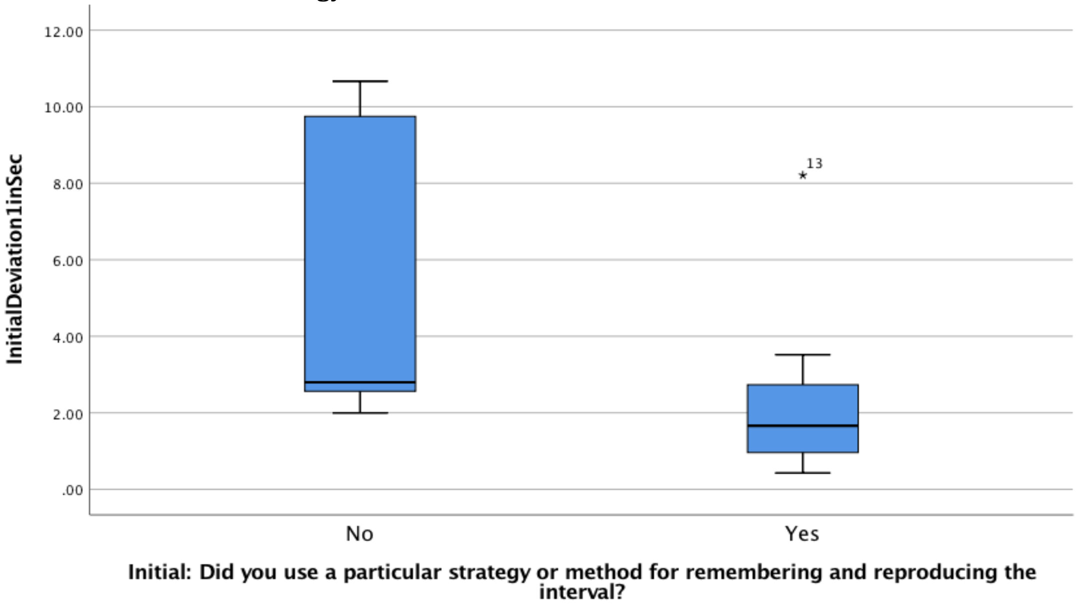
The use of a strategy

One of the first hypothesis made in this research, is that it is uncommon to consciously time an interval without the use of a strategy, and that counting is the most popular choice.

During the initial test, subjects were asked to time an interval without instruction, and afterwards were questioned on whether they made use of a conscious strategy. Of the 14 participants, 9 (64%) mentioned they made use of a conscious strategy, and 5 cases reported they did not (35.7%). 8 Subjects described a strategy based on counting (57.1%), and one mentioned to have used another strategy. This participant described the strategy as "*replaying an event from memory while listening*". The hypothesis that the majority of people uses a conscious strategy for timing an interval thus hold true, as well as the hypothesis that the most common strategy is counting.

A third hypothesis on the use of segmentation strategy during the initial test is that using a strategy improves accuracy in reproducing an interval of time. Looking at the results of the first reproduction, we can indeed say this is the case. On average the 5 participant who reported to have used no conscious strategy deviated 5,55 seconds from the 20 second interval (SD=4.27). The 9 subjects who reported to have used a conscious strategy on average only deviated 2,39 seconds (SD=2.39). Performing the Mann-Whitney test shows this difference is significant (P=0.027 (one-tailed), Z-score= -1.933). Below the range of responses is represented in the form of a boxplot. The outlier case 13 represents the single respondent previously mentioned, who used an alternative strategy not based on counting.

Figure 1. Difference in performance between participants who used a conscious strategy, and the ones who did not



In the second test, after coloring for three minutes, again a difference in favor of the use of a conscious strategy can be observed; subjects who used a strategy on average deviated 10.26 seconds from the interval (SD=13.37), the 4 subjects (one of the subjects mentioned an error in pressing the button during this test) who did not use a conscious strategy deviated on average 18.12 seconds (SD=12.24). The Mann-Whitney test shows the difference between the responses is not significant (p= 0.178 (one-tailed), Z-score= -0.926). Keeping in mind that in the second test only 4 responses are available in the group that used no conscious strategy, an 18% change the difference is a coincidence still seems low.

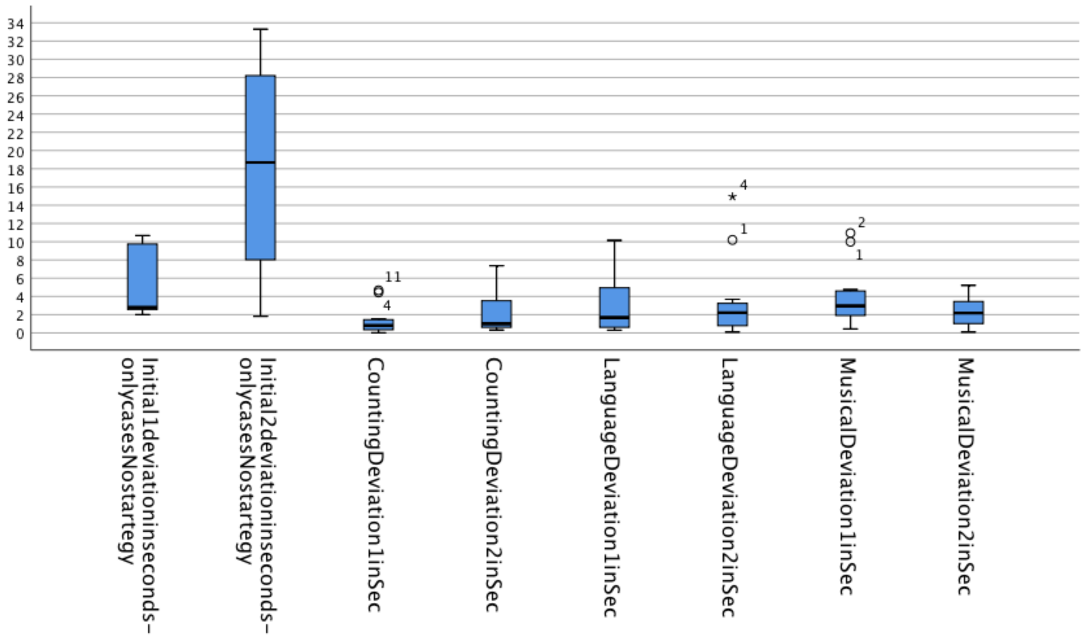
Looking at the data for both tests, it seems it is impossible to reject the hypothesis that the use of a segmentation strategy is beneficial for accurately reproducing a timing interval.

Differences between conditions

The main theory that is investigated with this experiment is that every strategy would engage a different timing system, which would become more plausible if different accuracies in reproducing timing intervals can be observed. Comparing the four different conditions can test the hypothesis that different strategies lead to different accuracies in the reproducing of the interval. Three of the conditions are formed by the tests that explicitly instruct the use of a particular strategy, and the fourth is made up by the responses of subjects on the initial test, who report to not have used a conscious strategy.

Representing the different test conditions in a boxplot, we can see some major and minor difference appear, especially in range of responses given.

Figure 2. Boxplot of distribution of responses for each of the tests (deviation in seconds from 20)



Looking at the averages for the four test conditions during the immediate test, the test before the distractor task, they are as follows; when no conscious use of a strategy is reported, the mean deviation is 5,55 seconds (SD.=4.27s), during the test with counting instructions mean deviation is only 1,26 seconds (SD.=1.49s), during the test that used the strategy based on language 2.85 seconds (SD.=2.96s), and during the strategy based on music the mean deviation was 3.73 second (SD.=3.11s).

The mean deviations for the second test conducted after performing a coloring task for three minutes, are as follows for the four conditions; No strategy used 18.12 seconds (SD.=13.37), using the counting strategy 2.06 seconds (SD.=2.12s), using the language strategy 3.34 seconds (SD.=4.16s), and using the musical strategy 2.35 seconds (SD.=1.55s). This last result is surprising; during the test using a musical strategy people deviate less from the interval after the three-minute task than before (3.73seconds (SD.=3.11s) versus 2.35 seconds (SD.=1.55s). It seems logical to presume the memory of an interval can only degrade over time, instead of improve. On closer inspection, there were 5 subjects who deviated less on the second test. Three participants experienced a minor improvement under a second (0.40s, 0.87s and 0.89s) and two improved their deviation with more than a second (1.80s and 8.15s).

Previously, the hypothesis of the benefits of using a strategy for reproducing timing intervals was tested, and on the basis of the data from this experiment, was considered valid. In the initial test without instruction, we saw in practice the ‘no conscious strategy’-condition was mainly compared with the strategy of counting, since most subjects who used a strategy used counting. Comparing the ‘no strategy’-condition with the other explicit strategy, we see a similar difference, where using a strategy seems beneficial reproducing timing intervals compared to using no conscious strategy.

The remaining three test conditions, namely the different tests in which the instruction was to explicitly use a certain strategy, are compared to test the hypothesis that ‘using a different strategy will lead to a different accuracy in reproducing an interval’. A Friedman’s test was performed to see if the responses in the three conditions differed significantly from each other in the first reproduction. This test showed the difference was very significant (p= 0.008, Chi-Square=9.571, df=2). Another Friedman’s test was conducted to compare the responses in the second reproduction, after the three-minute distracting task. In this part of the test no significant difference was found (p=0.931, Chi-square=0.143, df=2). Regarding the unexpected result in the second musical reproduction noticed earlier, a Wilcoxon test was performed only comparing the second reproductions of the counting and language conditions. Between these two conditions again no significant difference was found (p= 0.198, Z= -1.287).

In regards to the hypothesis ‘the use of a different segmentation leads to a different accuracy in reproducing a timing interval’, the conclusion is two-fold. For the immediate reproduction test, there seems to be a substantial effect size and the data is significantly different, which leads to the assumption the hypothesis is valid. For the second reproduction test, the mean deviation for the conditions based on the counting and language strategy seem in line of expectations, with the direction of effect being the same as in the immediate test with an extra deviation as is expected as an effect of memory degradation over time. However, this difference is not significant. The result of the second reproduction test in the musical strategy is highly unexpected. Thus in regards to the second reproduction test, we cannot accept the hypothesis.

Another hypothesis that was stated, was that using a musical strategy would lead to a higher accuracy in reproducing timing intervals. On the basis of this experiment, this hypothesis can be dismissed. Participants on average were 2.47 seconds less accurate in reproducing the interval using a musical strategy than using a strategy based on counting in the immediate reproduction test. Using the strategy based on language, participants were able to reproduce a time on average 1.59 seconds closer to the interval. In fact, in the immediate reproduction test, the musical strategy proved to be the least accurate.

Results in the second reproduction, after three-minutes passed doing the coloring task, are less clear in this respect, and will be reported on in the next chapter.

Looking at some of the individual scores, it is noteworthy that some are extremely accurate. Reproductions are recorded, with only 0.01, 0.07 and 0.08 seconds deviation from 20 seconds (using the counting strategy), and 0.11s deviation on two single responses using a counting and a musical strategy. Although there is a big change these single responses are caused by coincidence, it seems to suggest extreme amounts of accuracy can be achieved using all of the different segmentation strategies.

Memory decay

The aim of having two reproductions test for each condition, separated by an amount of time and the distractor test, was to investigate the hypothesis that different strategies would invite different ways of memory encoding. This assumption would be made plausible if the hypothesis 'Different segmentation strategies have different degradation of accuracy of timing reproduction' tested valid when comparing both of the tests. The underlying hypothesis of this statement was that timing reproduction accuracy lessened when more time passed. As seen before, this assumption does not seem to hold true for the musical condition, where 5 participants improved their accuracy over time. In regards to the decay of memory of timing intervals, the hypothesis was also stated that musical segmentation strategies would be best to maintain a high quality memory for timing. In this part, these hypotheses will be investigated.

First the effect size of the distractor task is computed. Using the mean of each task, we can say that average deviation for the participants who reported to not have used a conscious strategy, has grown with 11.68 seconds between both tests (SD.=15.79s, using a mean based on n=4 for both variables since 1 test is dismissed in the second test), during the test that used a counting strategy 0.80 seconds (SD.=1.97s), and during the test using the language strategy 0.49

seconds (SD.=3.73). During the test using a musical segmentation strategy, accuracy on average improved by 1.39 seconds (SD.=2.89). To see if the responses of the first and second test were significantly different, for each of the conditions a Wilcoxon test was performed. Since the hypothesis is one-tailed ('on the second test deviation is higher') p-values are cut in half. This leads us to conclude that only the responses on the musical test differ significantly from each other (p=0.011, Z=-2.291). The difference between both counting tests is not (p=0.099, Z=-1.287), as well as the difference between both tests using a language based strategy (p=0.2162, z=-0.785), and the initial test responses of subjects who reported to have not used a conscious strategy (N=4, p=0.072, Z=-1.461). However, since this last condition only has 4 cases, a p-value of 0.072 and an effect size of 12.56 seconds can be accepted as pointing toward a trend in the data.

Thus, from this data, it is not possible to say the accuracy declined significantly in any of the conditions that use an explicit strategy, and the hypothesis the accuracy of the interval reproduction was lessened by the time passed during the distractor task, on the basis of this experiment is invalid.

To compare if there was a difference between the three explicit strategies, a Friedman test was performed on variables that computed the difference between both tests within each condition. This test showed that there was no significant difference in the difference in responses (p=0.223, Chi-square=3.000, df=2). We thus have to reject the hypothesis that different strategies cause a different degradation of accuracy over a period of three minutes.

Musicians

One of the reoccurring topics in interval estimation and reproduction research is the question if timing cognition can be improved by training. Therefore the hypothesis 'musicians perform better in reproduction of timing' is adopted. As well, it is expected that musician are better able to adopt the musical segmentation strategy. 9 Participants reported to have received musical training (the follow up question showed all received multiple years of training (5+years)), and 5 reported to have no formal training. Below the results for each of the groups are displayed, with the groups with best accuracies being highlighted. As we can see, overall the musicians seem to perform slightly worse than none musicians, with the exception being the tests within the musical condition.

Figure 3. Table separating responses of musicians and non-musicians (deviation in seconds)

Av.Deviation (rounded up to two decimals)		**No training**	**Musical training**
No strategy 1 (N=5)	Mean	**10.21**	**2.45**
	SD	0.65(N=2)	0.41(N=3)
No strategy 2 (N=4)	Mean	**12.49**	**23.76**
	SD	15.07(N=2)	13.49(N=2)

Counting 1 (N=14)	Mean	**1.00**	**1.40**
	SD	0.57(N=5)	1.84(N=9)
Counting 2 (N=14)	Mean	**1.45**	**2.40**
	SD	1.81(N=5)	2.30(N=9)
Language 1 (N=14)	Mean	**2.41**	**3.09**
	SD	2.61(N=5)	3.27(N=9)
Language 2 (N=14)	Mean	**3.11**	**3.47**
	SD	4.07(N=5)	4.45(N=9)
Musical 1 (N=14)	Mean	**5.02**	**3.03**
	SD	2.98(N=5)	3.11(N=9)
Musical 2 (N=14)	Mean	**2.58**	**2.22**
	SD	1.43(N=5)	1.68(N=9)

Investigating the differences between the subjects that received musical training, and the subjects who did not, for each of the reproductions a Mann-Whitney test for independent samples was performed. These tests showed responses only differed significantly for the 'no-strategy'-test before the distractor task (p=0.0415 (one-tailed), Z=-1.732), and the musical test before the distractor task (p=0.0256 (one-tailed), Z=1.933). In these tests the average effect-size of receiving musical training being 7.76 seconds in the first case, and 1.99 seconds in the latter. For the second initial test without strategy (p=0.2195 (one-tailed), Z=-0.775), both the counting tests (p=0.2745 (one-tailed), Z=-0.600 and p=0.081 (one-tailed), Z=-1.400), both the language tests (p=0.2315 (one-tailed), Z=-0.67 and p=0.2315 (one-tailed), Z-0.733), and the musical test after the distractor task (p=0.3205 (one-tailed), Z=-0.467), no significant difference between the two groups can be accepted.

The hypothesis that musicians are better in overall reproduction of timing intervals thus must be rejected. In fact, looking at the data it seems on average this group scores slightly worse, but the difference is negligible. The non-musical test (no strategy reproduction 1), where musicians score significantly better should be regarded with suspicion, since the number of respondents in each group is too low to accept a general trend. In the test based on a musical segmentation strategy, musicians do tend to score higher in reproducing the interval. Even although the groups are rather small, the result for the immediate test is significant and the effect size is substantial (musicians on average have 39.6% less deviation). Therefore, on the basis of this data, it seems possible to accept the hypothesis that musicians are better at adopting a musical segmentation strategy compared to non-musicians.

Individual differences

On the basis on research on *absolute tempo* by Graton et al. (2005), we expected to encounter large differences in the timing performances of individuals. Graton et al. conclude, "*some individuals have the ability to retrieve temporal rate of an acoustic event without a reference*"(2005. P.16), and cautiously measure that 53% of their participants belong to this group. If timing performance is related to a discrete skill some people poses and others do not, and the distribution can be generalized to about half of the population, in this experiment some people should score consistently better than others. Therefore the individual differences in performance in this experiment are analyzed using the hypothesis that 'some individuals score consistently on the top of the distribution of scores, and some individuals consistently score on the bottom of the distribution of scores'.

Ranking the scores for each of the performed test, we see no such clear individual trends emerge. In fact, multiple subjects who rank first in one test score close to last in one of the other tests. To gain an objective measure to judge the hypothesis against, subject's test results are ranked in quartiles each representing 25% of performance. From these ranks, it can be conclude that none of the participants consistently scored in the top or bottom 25% of measured accuracies. Furthermore, none of the participants consistently scored in the top or bottom 50% of scores.

A multiple correspondence analysis was performed to see if there were individual patterns in the data that were not so apparent, and perhaps a single test condition might be responsible for not recognizing individual trends. However, no clear factors were found.

Therefore on the basis of this data, we must reject the hypothesis that some individual subjects perform consistently better or worse. There were however some single scores that seem noteworthy. For example, participant 8, who scored below 1 second deviation on 6 of the 8 reproductions, and subject 14 who scored below 0.5 seconds deviation in 5 of 8 tests.

Ease of use

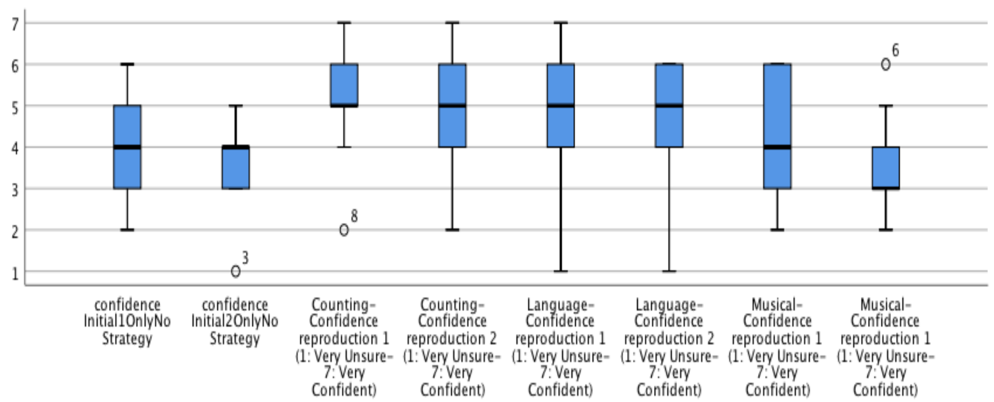
This experiment also wanted to investigate which segmentation strategy was felt to be the easiest to use, and which the hardest. The expectation was, that it would cost less concentration to use the musical segmentation strategy.

9 Subjects mentioned the counting strategy to be the easiest to use (64%), 3 subjects reported the text-based strategy to be the easiest (21.4%), and only 1 mentioned the music-based strategy as being the simplest to perform. One participant reported to believe both the counting and the text-based strategies were similar in their ease of use. 10 Participants (71.4%) found the music-based strategy to be the hardest to perform, while 4 mentioned the text-based strategy as being most difficult (28.6%). None mentioned counting as being the most difficult.

After completing both of the tests for each conditions, participant were asked to mark how confident they were their response matched the interval. The responses are represented below in a boxplot graph. We can recognize the counting strategy (5,36 and 5.07 out of 7) and the language strategy (4.64 and 4.64 out of 7) aspire the highest amount of confidence, and the subjects who used no strategy during the initial test were most unsure about their reproduction (4.0 and 3.4 out of 7). The musical strategy sparked an intermediate score (4.29 and 3.5 out of 7). Notably, average confidence in the response did not decline during the distractor task using the language strategy, while it did drop almost a full point using the musical strategy.

Two Friedman tests were performed to see if confidence-levels in each of the test conditions differed significantly from each other. This was the case for both the immediate reproductions (p=0.33, Chi-square=8.721, df=3), as well as for the reproductions after the three-minute period (p=0.044, Chi-square= 8.100, df=3).

Figure 4. Boxplot of reported confidence in the responses for each of the tests (1: Very unsure- 7: Very confident)



5: Reflection

Reflection upon literature

This research was performed to learn more about the human ability, or better the lack of ability, to encode the passing of time objectively. The observation that humans remembered time extremely subjectively, but at the same time posses great musical abilities seemed worth researching. After all, musical attributes are nothing but temporal patterns of air pressure, and every form of processing music seems to require great capabilities for storing these patterns in memory.

After a broad search through available research in multiple fields of study, it seems not much facts are yet uncovered about human timing cognition. There seems to be great promise in research with modern neuroimaging techniques, but what they uncovered until date seems to be that timing behavior is extremely complex, and involves a multitude of brain subsystems. An interesting avenue of research seems to be comparing the brain physiology of humans and animals, especially since the complex timing behaviors connected to music seem to be uniquely human.

Not all secrets of timing behavior will be uncovered by neuroimaging techniques alone. More than an intuitive mechanism, human timing cognition seems to also rely on complex conscious mechanisms, especially for longer durations. This seems particularly true, since it seems that we cannot store objective time as a discrete object in memory, but always seems to have need for a different medium to indirectly store temporal information. As well, in this regard, it might be that mechanisms for memory encoding of time are partly unique to a certain timing task, or even certain individuals. These points highlight the necessity of time cognition research in the field of behavioral psychology.

From available theories and models of time perception, in this paper I proposed a simplistic abstract model of timing cognition for longer intervals. This psychological model is based on the notion of the specious present, which is a reoccurring theme in time cognition research. This model proposes two distinct objects, which together make possible the timing of events of periods that exceed the approximately 2 second duration, a duration connected to the so-called specious present. The first part is a small component -of a duration within the specious present- consisting of a detailed, high quality, sensory representation, which indirectly stores temporal information. Examples might be the memory encoding of a pitch within the phonal loop working memory, or a pattern of motor-feedback from the articulatory muscles. The second component is formed by an efficiently encoded, large, abstract, and flexible structure of sequential information, that meaningfully connects the smaller components to each other, but in itself does not contain temporal information. Examples of such encodings can be expressions of relative regularity within a rhythm, the syntax of meaningful sentences together forming a narrative, or events, encapsulating other events in a causal relation. This way of understanding time perception is mostly influence by the paradigm of models that see no need for a 'clock' mechanism, while at the same time leaving room for such a 'clock' mechanism at the basis of timing behavior.

This model is simplistic, and might feel obvious, but it does seem to do justice to the many ways we think about time without being able to store objective time a distinct object in the mind. This model should be regarded as opposed to a singular, central, discrete timing cognition and memory used for all time-sensitive behavior. Although abstract, this model can be specified and made more concrete by the use of explicit segmentation strategies. Using explicit segmentation strategies, the model can be tested in an interpretive fashion, with the hope of learning more about the different ways of memorizing objective time.

An attempt was made to test this, by means of a small sample exploratory experiment. Reading the reflections on this experiment, the reader must realize this experiment is done using only 14 participants, and therefore the recognized trends are not immediately generalizable for the complete population. That said, the fact that some clear trends are visible in the data from this experiment should not be understated, and the results of this research can be used to highlight phenomena that can be scrutinized in future research using larger samples sizes.

Reflections of the experiment

The primary aim of the experiment undertaken was to see if objective timing information could be indeed encoded in the memory in different ways. To this extend three segmentation strategies were compared to each other, each trying to invite to use a different way of encoding of objective timing information.

First, the question was answered if the use of such a segmentation strategy was a natural way of perceiving and encoding time in the mind. As was expected, the majority of participants timed the interval using such a conscious strategy (64% of the sample), although the amount of people who claimed to have used no conscious strategy, but relied on 'intuition', was higher than expected (35.7% of sample). However, that the majority of participants took such an approach without instruction should be enough evidence to claim that segmentation strategies are a natural part of conscious time cognition. As theorized, most people used a strategy based on counting, but one participant reported having taken the approach of trying to recount a specific memory similarly during both exposure and reproduction of the interval. This shows that to at least some people, other techniques feel natural, which gives plausibility to other types of segmentation for gaining sense of objective time.

The subject who reported to have used the alternative technique did not score well in reproducing the interval. The other participants, who used a segmentation strategy, in this case counting, overall performed better than those who did not. All participants were clearly instructed to concentrate on the passing of time. This difference in performance could be explained by the mind needing something to indirectly store time with. The counting strategy gives time a medium to be encoded in memory. Even while consciously concentrating on the passing of time, it seems without internal or external events, registration of objective time seems to be more inaccurate. This observation seems to give plausibility to the assumption underlying this research, which is that time cannot be stored as a discrete object in the mind. As well, perhaps overstretching, it may be carefully seen as discrediting to the paradigm of models of time perception that uses a discrete clock mechanism, and use a pacemaker-accumulator mechanism for explaining time perception. Such a conscious counting strategy can be seen as very similar to the unconscious mechanism described in this model, and seems to be working. However, the people who did not use a conscious strategy apparently used an unconsciously timing system, which lead them to reach a lower level of accuracy. Of course, it could very well be that allocating more resources to such a system leads to the measured higher accuracies.

Comparing the three segmentation strategies, the first observation is that they all worked to a certain extend. All strategies seemed to be able to produce accuracies better than using no conscious strategy, as well as some results extremely close to the interval to be reproduced. At the same time, differences in accuracies can be recognized. This gives merit to the hypothesis that objective time can be stored using different components discussed in the proposed model. There are two opposing arguments for accepting this hypothesis. Firstly, it can be that there is a single alternative underlying timing and encoding system, and the different segmentation strategies only influence performance of this timing system, by facilitating or disrupting this system. For example, an alternative hypothesis could be that during every test a counting strategy is used, and the difference in scores is due to the distraction posed by trying to follow the other instructions. This seems unlikely, in first because of the difference seen between group that used no conscious strategy and the group that counted, and secondly because of the explicit nature of the segmentations strategies. Subjects were asked to perform every strategy out loud, which would make it hard to perform another conscious strategy simultaneously.
A second opposing argument against accepting the hypothesis that the strategies invited different ways of encoding time in memory, on the basis that all strategies performed, is that it could be that the instructed strategies were too similar. All materials used ended up having a regular rhythmic component, since the text used was a rhyme. Therefore, all these strategies entailed a sense of temporal regularity. Instead of completely different from one another, all strategies were placed on a scale of rhythmicity. As well, in the proposed model, the language strategy stores indirect temporal segments derived from the phonal loop, which in turn relies on motor-feedback from the articulatory muscles. It can be argued counting out loud is very similar in this sense, only differing in the larger structure (syntax and narrative versus decimal system) used to connect these segments sequentially. Future research on segmentation strategies might benefit from choosing more different strategies, for example based on causality, in order to extrapolate differences in memory encoding. As well, strategies based on explicit muscle movement might be considered. It would be telling if a certain segmentation strategy turned out to be not performing, that is working worse than using no conscious strategy.

The experiment contained a three-minute coloring task, with the aim of distracting subjects by forcing them to use a different modality, as well as letting some time pass. The hope was this would allow testing for how the memory of the interval was encoded in a different part of memory, from working memory to longer-term memory. This way, the experiment hoped to extrapolate the differences of the memory representations formed in relation to each of the different strategies. This experiment design factor did not work out, and no significant decay of memory has been observed. This means nothing about the differences in decay between the strategies can be said. Some differences between the immediate reproduction and the one after the three-minute task can be observed; so it might be a future experiment with a larger sample size might be more telling in this respect. It may however also be that a different design must be used to say something about long-term memory of absolute timing, for example, leaving more time in between interval exposure and reproduction.

Another important observation is that the hypothesis about the accuracy of musical temporal memory, which started this research, seems invalid. In this experiment, using a musical segmentations strategy results in the least accurate reproductions compared to both other conscious segmentation strategies. As well, contrary to expectations, musical segmentation was also reported to be the most difficult to use. This last observation might also point toward the reason why the accuracy of reproduction using a musical strategy was lowest. It might be that the material being used in this strategy was not familiar enough to be used with greater success than a strategy like counting, which is practiced often. Within the setting of this experiment, participants were made to learn the music by humming along with the fragment for at least three times. It could be argued that this is not enough to make it usable as a segmentation strategy. This argument can be countered with the fact 12 out of 14 participants mentioned to be already familiar with the piece. Furthermore, recording of the test are made, and although no objective analysis of these recording has been made, it can be said all participant hummed the song along quite accurately during reproduction of the interval (both in terms of tempo and melody). Still, recalling the material could take up a lot of concentration, next to paying attention to the interval, and the strategy will benefit from further familiarizing subjects with the segmentation material.

The same can be said about the text that is used. Only half (7 out of 14) was familiar with the text before the experiment. However, most of the people repeated the text correctly, or made small mistakes (one extra word) consistently, which should not interfere with the segmentation strategy. However, listening to the recording it is clear some people had difficulty retrieving the text, and practice should improve the accuracy of this strategy.

As well, it must be pointed out, that counting is shown to perform best only in the exact setting of this experiment. That is, estimating a single interval of 20 seconds. It might be that the use of a different interval duration, or different timing task leads to different results. For example, if music provides "*a 'ruler;*

against which the temporal position of a test tone can be judged accurately" (Repp, 2011), a more complex timing task may benefit from the resolution provided by the multiple rhythms in different timescales, present in natural music but not in the simple rhythm used in the counting strategy. As well, the influence of the three-minute distracting task using the musical strategy raises some questions. It was expected music should be helpful in retaining temporal information in long-term memory. The observed results in the second test seem to be strange (better than on the immediate test), but leave some room for future research to investigate this hypothesis.

One other interesting observations of this research, is that no large individual differences in reproduction accuracy can be recognized. It is expected that a similar research with a larger sample size might show these differences more clearly. Getting a picture of the distribution of timing skills might be telling if cognition of timing is more intuitive or conscious. Normal distribution might be expected if timing performance is caused by an underlying biologic system, while a conscious strategy might show a different pattern in distribution. In this regard, the observed difference between musicians and non-musicians using the musical segmentation strategy seems telling. The fact that training seems to help in using musical segmentation, but not in the other strategies seems to point toward a more high level conscious timing system. An other explanation could be that a more 'music specific' biological timing system is improved by training.

Concluding, it can be said this particular experiment is limited in descriptive power and generalizability, but has showed that using an experiment design based on explicit segmentation strategies is worth undertaking. Although it has not proven the power of music to store objective timing information, it has shown that it is plausible objective temporal information can be encoded in different ways, with music being one of them.

6: Acknowledgments

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Attachment – Questionnaire

On the next pages the questionnaire used in the experiment is printed.

Test #1

Questions test #1

- **How confident are you that your first response matches the interval time, in the test taken before making the drawing?**
  Please give the answer by placing a mark on the scale where 1 represents 'very unsure', and 7 represents 'very confident'.

	1	2	3	4	5	6	7	
Very unsure								**Very confident**

- **How confident are you that your second response matches the interval time, in the test taken after making the drawing?**
  Please give the answer by placing a mark on the scale where 1 represents 'very unsure', and 7 represents 'very confident'.

	1	2	3	4	5	6	7	
Very unsure								**Very confident**

- **Did you use a particular strategy or method for remembering and reproducing the interval time? If so describe the strategy you used.**

	No, I did not use a strategy
	Yes, I did use a particular strategy

Description of the strategy used:

Test #2

Questions test #2

- **How confident are you that your first response matches the interval time, in the test taken before making the drawing?**
  Please give the answer by placing a mark on the scale where 1 represents 'very unsure', and 7 represents 'very confident'.

	1	2	3	4	5	6	7	
Very unsure								**Very confident**

- **How confident are you that your second response matches the interval time, in the test taken after making the drawing?**
  Please give the answer by placing a mark on the scale where 1 represents 'very unsure', and 7 represents 'very confident'.

	1	2	3	4	5	6	7	
Very unsure								**Very confident**

- **Did you find it difficult to use the strategy as instructed?**
  Please give the answer by placing a mark on the scale where 1 represents 'very difficult', and 7 represents 'very easy'.

	1	2	3	4	5	6	7	
Very difficult								**Very easy**

Test #3

Questions test #3

- **How confident are you that your first response matches the interval time, in the test taken before making the drawing?**
  Please give the answer by placing a mark on the scale where 1 represents 'very unsure', and 7 represents 'very confident'.

	1	2	3	4	5	6	7	
Very unsure								**Very confident**

- **How confident are you that your second response matches the interval time, in the test taken after making the drawing?**
  Please give the answer by placing a mark on the scale where 1 represents 'very unsure', and 7 represents 'very confident'.

	1	2	3	4	5	6	7	
Very unsure								**Very confident**

- **Did you find it difficult to use the strategy as instructed?**
  Please give the answer by placing a mark on the scale where 1 represents 'very difficult', and 7 represents 'very easy'.

	1	2	3	4	5	6	7	
Very difficult								**Very easy**

- **Were you familiar with the text that was used?**

	Yes, the text was familiar
	No, I did not recognize the text

- **In the box below, please write down the text the way you remembered it**

Test #4

Questions test #4

- **How confident are you that your first response matches the interval time, in the test taken before making the drawing?**
  Please give the answer by placing a mark on the scale where 1 represents 'very unsure', and 7 represents 'very confident'.

	1	2	3	4	5	6	7	
Very unsure								**Very confident**

- **How confident are you that your second response matches the interval time, in the test taken after making the drawing?**
  Please give the answer by placing a mark on the scale where 1 represents 'very unsure', and 7 represents 'very confident'.

	1	2	3	4	5	6	7	
Very unsure								**Very confident**

- **Did you find it difficult to use the strategy as instructed?**
  Please give the answer by placing a mark on the scale where 1 represents 'very difficult', and 7 represents 'very easy'.

	1	2	3	4	5	6	7	
Very difficult								**Very easy**

- **Were you familiar with the piece of music that was used?**

	Yes, the music was familiar
	No, I did not recognize the music

- **Did you like the piece of music that was used?**

	Yes, I found the music enjoyable
	No, I did not like the music

Questions #5

Questions #5

- **Which strategy you found the easiest to use?**

Counting along	
Using text	
Using music	

- **Which strategy you found the hardest to use?**

Counting along	
Using text	
Using music	

- **How would you judge your skill in the English language?**
  Please give the answer by placing a mark on the scale where 1 represents 'Beginner level', and 7 represents 'Expert level'.

	1	2	3	4	5	6	7	
Beginner								**Expert**

- **Did you receive musical training, or played an instrument, and if so for how many years?**

	No, I have had no musical training
	Yes, I received musical training/played an instrument

Years I played an instrument:
