Reproducing the Passage of Time: Effects of Stimulus Complexity, Quantity, and Cognitive Interference

MSc Thesis *(Afstudeerscriptie)*

written by

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Abstract

The aim of this work is three-fold: first, to provide a brief historical account of time in cognitive psychology focusing primarily on the significant contributions of Jean-Marie Guyau, William James, and Henri Bergson. In examining the historical ideas of these influential writers, the present work hopes to furnish the psychology of time with a firm theoretical framework that clarifies the motivation behind subsequent analyses. Second, the various models and perspectives proposed that attempt at explaining human psychological time will be thoroughly examined. This will be accomplished by a critical consideration of some of the important models proposed to explain psychological time: Clock models (chronobiological models, scalar-timing model, attentional-gate model), and clock-free models (storage-size model, contextual-change model, coincidence-detection model). Finally, a psychophysical experiment that tests some of the theories and assumptions concerning the subjective expansion and contraction of our subjective flow of time will be reported. This experiment, using the method of reproduction, essentially tests how different factors (visual stimulus complexity, stimuli quantity, cognitive interference) can influence later duration reproductions. The results wills be discussed in light of the historical ideas that helped shape the psychology of time, as well as the proposed models that aid in providing an adequate explanatory account of interval-timing behavior.

Contents

1 Introduction

In 1891, in his comprehensive historical exposition of the psychology of time, Herbert Nichols beautifully summed up the complex state of affairs in attempts to explain the mystery of time:

> "Casting an eye backward, we can but be struck by the wide variety of explanations offered for the time-mystery. Time has been called an act of mind, of reason, of perception, of intuition, of sense, of memory, of will, of all possible compounds and compositions to be made up from all of them. It has been deemed a General Sense accompanying all mental content in a manner similar to that conceived of pain and pleasure. It has been assigned as a separate, special, disparate sense, to nigh a dozen kinds of "feeling," some familiar, some strangely invented for the difficulty. It has been explained by "relations," by "ear-marks," by "signs," by "remnants," by "struggles" and by "strifes," by "luminous trains," by "blocks of specious-present," by "apperception." It has been declared a priori, innate, intuitive, empirical, mechanical. It has been deduced from within and from without, from heaven, and from earth, and from several things difficult to imagine as of either." (Nichols, 1891, p. 502).

Despite the rough and complicated landscape governing the psychology of time, a striking amount of progress has been made since in our characterization and understanding of the phenomenon[1] of time. From a methodological and a conceptual standpoint, the study of time has transcended what Michon called the age of "the psychophysics of duration" (Michon, 1988, 1990), an endeavor that occupied a century's worth of research since the inception of time psychology.

Experimentally, this was manifested in the curiosity that our subjective sense of time seems to fly past us at times, and seems to stretch on indefinitely at other times, leading time psychologists and psychophysicists to empirically test this phenomenon under several different conditions - this was primarily accomplished by employing a methodological toolkit that required participants to compare, produce, reproduce, or verbally estimate durations (Block & Zakay, 1997; Zakay & Block, 1997; Macar, 1996; Zakay, 1990; Hicks, Miller, & Kinsbourne, 1976). This, according to Michon (1990) should come as no surprise, as the study of how perceived duration differs under certain biological and environmental constraints is one of the hallmarks of the dynamic quality of our everyday experiences.

The arrival of cognitive psychology (Michon, 1990) had overturned the psychology of time from the reductionist behavioristic stance that viewed human subjects as black-boxes (mysterious information processors) that receive input (e.g., a target interval) and give some output (e.g., a duration estimate), by placing greater emphasis on the "temporal aspects of cognition and the cognitive aspects of temporality" (Michon, 1990, p. 38). This had resulted in greater interest with the rhythmic aspect of time (motor activity) (Semjen,

[1] We realize that with such a reference, it could be objected that we are implicitly asserting that time is a single unified phenomenon. Despite the multifaceted nature of time, we will adhere to the convention of referring to time qua Time as a unified thing, and only when the occasion calls for otherwise, we will elaborate accordingly. This becomes rather important when we later consider the neural implementation of time.

1996; Summers & Burns, 1990), formalization of action planning and events (vanLambalgen & Hamm, 2005; Allen, 1984), the temporal organization of language and speech (Ackermann, Mathiak, & Ivry, 2004), cognitive time management (Rubia & Smith, 2004), temporality of music (Jones, 1990), temporal features of autobiographical and episode memory (B. Levine, 2004), mental time travel (Suddendorf & Corballis, 1997), the neural basis and neural encoding of time (Karmarkar & Buonomano, 2007; Buhusi & Meck, 2005; Ivry & Spencer, 2004), time estimation and aging (Lustig & Meck, 2001; Craik & Hay, 1999), temporal perspective in psychiatric disorders (Mo, 1990), neuropsychopharmacological alterations of subjective time (Ruey-Kuang Cheng, 2006; Meck, 1996), amongst other topics. In particular, understanding the relationship between our subjective mode of time and how it relates to the structure, content, and organization of our memories has been of particular importance, and what the remainder of this exposition will focus on.

The aim of this work is three-fold: first, to provide a brief historical account of time in cognitive psychology focusing primarily on the significant contributions of Jean-Marie Guyau, William James, and Henri Bergson. Second, the various models and perspectives proposed that attempt at explaining human psychological time will be thoroughly examined. Finally, a psychophysical experiment that tests some of the theories and assumptions concerning the subjective expansion and contraction of our subjective flow of time will be reported. By closely inspecting the historical ideas that helped shape the psychology of time as well as the various models proposed in explaining the subjectivity of time, the present investigation hopes to bring together field- as well as domain-specific theories under a unified cognitive umbrella. This essentially involves an appreciation of the different approaches undertaken in the study of psychological time - these fall under the following broad categories[2]: Clock models (chronobiological models, the scalar-timing model, the attentional-gate model), and clock-free models (storage-size model, the contextual-change model, the coincidence-detection model). After a detailed inspection of the respective models, a psychophysical experiment using the method of reproduction that tests three separate manipulations (effect of stimulus complexity, stimulus quantity, and higher-order cognitive interference) on human duration estimates is presented. After showing the results, the findings of the experiment will be considered both in light of the historical ideas that shaped the psychology of time as well as the several models proposed to explain the plastic character of psychological time. Below, a brief historical account comprising primarily the pre-1950 influential ideas of Jean-Marie Guyau, Henri Bergson, and William James is given.

[2]Such a categorization is far from strict, as many of the emphasized elements of the models seep into the others, but for explication purposes, it makes matters easier to allow for such partitioning.

2 History of Time in Cognitive Psychology

2.1 Contributions of Jean-Marie Guyau, William James, and Henri Bergson

There are three fundamental questions one can ask about time: what is the nature of time (i.e., is it real or an illusion, and what is the 'stuff' it is made of), where does it[3] come from, and what purpose/function does it serve? The first of these questions is beyond the scope of this work, and will be left largely unaddressed[4]. The other two questions however, are of relevance for the present investigation.

There are two differing scientific perspectives on the issue of where time comes from: theories that posit that time is 'a priori' (nativist perspective) and theories that maintain that time, in some manner related to our cognition (empiricist perspective), is a mere outgrowth of experience (Roeckelein, 2000). Nativist theories posit that we are somehow born with temporal equipment, and as a result, temporal experience is provided by the mind, which in turn structures our experiences with the world. Such a view places the independent status/existence of time at the forefront of our experiences. Like space[5], time in the nativist perspective is understood as a primordial dimension, ever present with us. Time then, a universal primitive, serves to structure our experiences with the world - through temporal coordination and organization of the activities we engage in on a day-to-day basis. This perspective is in direct contrast with the empiricist claim, where time is perceived due to our cognizing abilities, an emergent property of experienced events. Such a view necessitates the conclusion that time exists in virtue of having a mind that is dynamically interwoven (through experience) with the world, and not as a precondition for the mind to exist (Roeckelein, 2000). Here, time is a product of our cognition, an evolutionary adaptive construct that serves to keep us in tune with our environment (Michon, 1996, 1990). As will become evident, it is this latter view that will resonate throughout the present investigation, as seen through the historical lenses of philosopher Jean-Marie Guyau and psychologist William James.

The French social philosopher Jean-Marie Guyau, focusing on the empirical development and origin of the idea of time, was concerned with bridging the notion of time to how humans process information. Questioning the ontological status of time, he propounded that time itself does not carry an independent existence in the universe, but is rather a product of the events that are themselves embedded in time (Roeckelein, 2000). As a result, time is a 'cognitive' manifestation, that arises out of the events that we experience in our lives - time, in this vein, is not a prior condition of our being, but a concomitant consequence of our experiences with the world. Michon, in a review of Guyau's *La gense de lide de temps* (The Origin of the Idea of Time), quotes his concluding remarks on the psychology of time:

[3]The use of the pronoun 'it' here presupposes that time is one thing - a view we do not wish to definitively endorse, yet we will maintain such a convention for explanatory ease.

[4]Some might believe that if time does not have an independent existence from the mind/brain, then it is necessarily illusory. We do not share this view, and hence a discussion of the reality of time is a deeper philosophical question that escapes the scope of this work.

[5]We will refrain from discussing the independent existence of space, nor will we delve into the metaphorical theory of representation that claims that time is derived from space (but see Lakoff & Johnson, 1980 and Michon, 1990, p. 47-48).

> "Time is not a condition, but rather a simple product of consciousness. It is not an *a priori* form that we impose on events. Time as I see it, is nothing but a kind of systematic tendency, an organization of mental representations. And memory is nothing but the art of evoking and organizing these representations. Time, initially, is no more intrinsic to our mind than it is to an hourglass" (1988, p. 163).

At its heart, the problem Guyau faced was how we can conceptualize or construct the flowing nature of time, for we not only lack the sensory apparatus necessary for accomplishing such a feat, but also what our senses provide us is fundamentally static input. By subtracting time from our everyday experience, we are left to imagine a world with mere visual, tactile, auditory, olfactory, and gustatory snapshots, that are intrinsically discontinuous. This very same problem was encountered by William James (James, 1890) during the same period, when he posed the question of how a succession of ideas can ever give rise to the idea of succession?

The French philosopher Henri Bergson, concerned by the very same problem that occupied Leibniz, Locke, James, and Guyau (Michon, 1988), believed that it is in fact "impossible to derive the dynamic streaming of experienced time from the ordered but inherently static impressions - the *differences, transitions,* and *intensities* - provided by physical reality" (p. 164). Bergson's response is that there exists a metaphysically independent 'lived duration', that is synchronized with the events we experience, yet does not have to be causally dependent on them - for Bergson, the dynamical flow of time as we experience it transcends that which is symbolic and representational, and is instead the "existential form of consciousness" (Michon, 1988, p. 165). Primarily reacting against the scientific and mechanistic ideology characteristic of the late 19^{th} and early 20^{th} century (Roeckelein, 2000), he distinguished between two aspects of time: chronological time and duration. The former, an abstraction symbolizing space, is a mere social utility that has been artifacted to augment our lives - by ordering and structuring our everyday experiences (e.g., calenders, mechanical clocks, etc.). In contrast, 'Duration' for Bergson is, as mentioned previously, an immeasurable flow that is indistinguishable from the essence of life - a fluid "progression of time where past, present, and future are dynamically fused and dissolve into an unbroken flux" (Roeckelein, 2000, p. 113).

Scientifically, Bergson's ideas perhaps do not have a place in the cognitive psychology of time - by elevating duration to the realm of metaphysics, his contributions, aside from speculating on the fundamental importance of 'Duration' for the construction of the Self and emphasizing the complex endeavor in understanding the perception of duration, are left empirically null. Guyau, on the other hand, had underscored the importance of duration by invoking cognitive processes, whereby the flow of time is an intellectual construct. If time then is a product of our cognition, it brings to question the reality of time - is time an illusion, albeit a believable one? Perhaps it is an illusion in so far as we cannot directly perceive time in the world, but there seems to be little doubt that that the flow of time is cognitively real, in virtue of our dynamic coordination and tuning with everyday reality. As Michon (1988) states, our awareness of the flow of time is functionally adaptive, permitting us to deal with "whatever temporal contingencies there may be in the external world" (p. 166). However, what exactly are these temporal contingencies, and what kind of bearing do they have on our cognitive apparatus? On what grounds can duration *per se* claim its real or cognitive autonomy?

James (1890) believed that duration is the unit by which our perception of time is composed of - the 'specious present', by which we are able to probe the past and anticipate the future. It is because of this '*duration-block*' as it were that one can apprehend the relation of succession. To elucidate by analogy, consider sitting on a train and looking out the window - you can recollect the scenes that have flashed by, and anticipate the scenes to come. This window of duration, so to speak, is what allows us to perceive order, i.e., what came *before* and what came *after*[6]. To give an example, if looking out the window one were to see a museum, and later a television station, despite that such memories are no longer part of the specious present (the window of duration reflected in virtue of our being at any block in time), one can infer the relations between the two events - that is, the event of seeing the museum occurred *before* the event of seeing the television station.

Taking the analogy of the train a step further, it becomes clear that the trains velocity is of paramount importance: How slow must the train travel so that the observer has ample time to decompose, store, and later retrieve the witnessed event? What is the velocity by which the mind processes information? Given that there is a standard processing velocity, what is the maximal and minimal deviation from such a standard exhibited across individuals[7]? For James (1890), taking after Wundt's work in attempting to determine the "maximal extent of our immediate distinct consciousness of successive impression" (p.612), states that the specious present, with its backward and forward edges, centers around approximately twelve seconds (but see (Block, 1990) for a review on more recent findings regarding the upper and lower limits of the 'psychological present'). However, the notion of the specious present is vague, and leaves unspecified what it is that occupies such duration (although James does devote a few pages to distinguish duration limits pertaining to different sensory modalities).

Over the past few decades, the notion of the specious present has come to be replaced by the theoretical cognitive scientific concept of working memory, a limited-capacity system "which temporarily maintains and stores information, supports human thought processes by providing an interface between perception, long-term memory and action" (Baddeley, 2003, p. 829). This working memory system, comprises three separate components, a supervisory subsystem and two memory subsystems: a central executive subsystem on the one hand, and the phonological loop and the visuo-spatial sketchpad on the other; but also possibly a fourth memory-based subsystem that is still under investigation, the episodic buffer (Baddeley, 2003, 2000). A closer look at the concept of working memory and how it pertains to the present work will be discussed later [see Section: Present Study].

Why does the subjective flow of time expand at times, and contract at other times? What is the driving force behind the variability in the duration-window,

[6]See McTaggart (McTaggart, 1908) for an in-depth discussion on the distinction between two useful constructs, the A-series (which orders events by their position in the past, present, or future) and the B-series (which orders events based on whether they came before or after each other), and whether the A-series is an illusion we've created.

[7]As will be shown later, these are similar questions that psychopharmacologists interested in the plasticity of subjective time seek to answer, by means of administering different psychoactive agents such as dopaminergic agonists (L-Dopa) and antagonists (Haloperidol) to different patient or healthy populations.

i.e., what influences the velocity of the analogical train? More precisely, how does the variability of the duration-window affect our duration estimates? Michon (1988), in his review of Guyau's contributions identified three characteristics that influence our perception and retention of duration. These characteristics are an off-shoot from the assumption that our cognitive processing, which is responsible for providing and shaping our sense of time is sensitive to exogenous factors. These characteristics are: a) Metrical aspects of events, that are indicative of the quantity and stochastic properties of event composites. b) Syntactic aspects representative of the structural relations that glue events together by the parametric specification of the rhythmic structure of event sequences. c) Semantic and pragmatic aspects which specify the emotional, cognitive and evaluative canvas by which events happen. Each of these aspects can influence our experiential subjectivity and awareness of the passage of time (Michon, 1988), and it will be shown later that indeed, these aspects provide some of the rudimentary building blocks for our subjective alteration of time under certain empirical manipulations [see Section: Present Study].

2.2 Four Important Guyauian Pillars of Time Psychology

Michon (1988), highlights seven pillars of time psychology that are sufficient in providing an adequate theory of psychological time. Briefly, these are the following:

1. A functional stimulus of our sense of time must be specified, that describes the external (environmental) stimuli by which our experience of time is constructed.

2. The levels of explanation used in the theory should be specified (functional architecture, functional design, intentional and rational behavior).

3. Distinguishing between explicit (slow/flexible, deliberate, accessible to conscious awareness) and implicit (fast/rigid, automatic, inaccessible to conscious awareness) temporal representations.

4. Discerning the role of dynamic memory, which organizes events as belonging to the past, present, or future[8].

5. Specification of the role of spatial analogy or metaphor in the temporal analysis.

6. Specification of the modes of representation and the rules that operate on such representations.

7. Specification of the ontogenesis of time by elucidating the mechanisms that give rise to our temporal experience across the lifespan.

While all of the pillars importantly fare into psychological time research, the present work is concerned primarily with the first four points. Each of these will be briefly described below.

Specification of the functional stimulus: Under any empirical inquiry into the plasticity of psychological time, the choice of appropriate stimuli is highly

[8]cf., McTaggart's (1908) A-series.

important (see (Fetterman, 1996) for a Gibsonian approach to stimuli construction and choice). Varying the complexity of the stimuli (visual or auditory) employed in an empirical analysis, manipulating the order of the stimuli, and accounting for the differences, transitions, and intensities (Michon, 1988) of the stimuli can influence the behavioral outcome of people in an experimental situation. The important role that stimuli play in shaping our experience of time was already anticipated by Guyau (Roeckelein, 2000), when he provided a set of characteristics that serve as a bedrock for the construction of temporal experience: a) intensity (or magnitude) of the stimuli b) number of stimuli c) attention paid to stimuli d) (degrees of) differences between stimuli and e) expectations elicited by the stimuli. These characteristics have seeped into much of the research in time psychology (especially duration estimates), and will be elaborated on in great detail when discussing the experimental manipulations chosen for the current study. [see Section: Present Study].

Distinguishing between levels of explanation: Accounting for and distinguishing between the different levels of discourse is extremely important, as they could potentially cloud the theoretical underpinnings relevant for any psychological time research (see (Dennett, 1988) for potential dangers of confusing the different levels of explanation in cognitive science, and (Bechtel, 1994) for a comprehensive description of how explanation and description in cognitive science should develop). Michon (1988) distinguishes three levels of discourse in time psychology: a) Specifying the underlying architecture of clocks and regulators b) Approaching time as a product of temporal information processing c) Understanding time as the product of a dynamic and self-organizing structure. Each of these levels, while independent (i.e., can be studied independently), require that they meet the constraints of the underlying architecture - in this case, to fulfill the psychobiological requirement of an internal clock(s) mechansim[9]. The striking similarity between the three levels of discourse Michon (1988) distinguishes and David Marr's (1982) sophisticated neuroscientific investigation into the different levels that a cognitive system can be described warrants some explication.

Marr (1982), basing his work on the analysis of our visual system, proposed three distinct levels by which a cognitive system can be described: the computational level, the representational/algorithmic level, and the implementational level. The computational level details the kinds of functions that the system is to perform - this parallels the view of time as a dynamic context-embedded intentional/semantic entity. This level surfaces questions concerned with the goal of the computation, its appropriateness, and the logical curtain governing the strategies by which the computation is carried out. The representational/algorthmic level details the procedures by which temporal information is generated and transformed - this is reminiscent of viewing time as information, to be processed as input and transformed into some output. This level concerns detailing the procedural specification of the computational theory (i.e., the dynamic, semantic aspect of temporality), in particular fleshing out the representational input and output by which an identified algorithm can be used for such transformation. Finally, the implementational or hardware level concerns how representations and their corresponding algorithms can be physically realized

[9]Constraining a psychological time theory by accounting for an internal clock is sometimes violated in clock-free models of psychological time (see for e.g., Karmarkar & Buonomano, 2007

(by specifying the appropriate mechanism) in an actual system (e.g., biological brains) - this is reminiscent of expounding the physical architecture of internal clocks and regulators. As will become evident later, the occupation of the psychophysics of duration has restricted itself to the representational/algorithmic level, where subjects in an experiment are understood as temporal information processors that receive a standard duration, and have to elicit the correct target duration by means of production, reproduction, comparison, or verbal estimation[10].

Implicit versus explicit representations of time: The distinction between implicit and explicit processing[11], whether of time or other cognitive behaviors is of particular relevance in explaining phenomena in cognitive science, and deserves special attention in the context of the psychology of time. This is primarily because much of our behavior does not rely on explicit representations this is especially salient in temporal behavior. In planning and coordinating our actions, it is beyond question that we are situated in and execute our actions in time. For example, in writing this paragraph, there must be some temporal representation or representations at all times, albeit implicit - consider the multiple keystrokes required to write a single sentence. These keystroke actions abide by a (conventionalized) temporal pattern, a sequence of movements that embody the written sentence. In writing this sentence, one need not be aware of the temporal relation that holds between the respective keystrokes on the keyboard - it is automatic, fast, and apart from the current discussion which brings the sequential motor behavior of key-pressing to conscious awareness, is by and large implicit. As Michon (1990) writes:

> "The temporal structure or *temporality* of behavior, that is, their dynamics, their timing, their tuning to the objects and events that they are about (the so-called intentional objects), is not normally accessible to introspection. The temporality of our behavior is, in other words, cognitively impenetrable. An action *expresses* time but is not defined by any temporal representation, that is, by relations in terms of duration, order, date, and so forth, in a person's consciousness (p. 39)."

By contrast, the explicit mode of temporality, is slow, deliberate/flexible, and accessible to conscious awareness. This mode handles aspects of time viewed as past, present, future, order, and duration (Michon, 1990, 1988). According to Michon (1990, 1988), this is the conceptual structure that governs our awareness of temporal relations between events and our conscious reflection/introspection of the actions we execute. By reflection, our action (which is the object of our reflection) becomes an intentional object situated in the present 'now' where the action is being executed - this 'now' becomes an explicit temporal object (with order and durational properties) that can be woven into the temporal dimensions of past, present, and future. Reconsidering the aforementioned keystroke example, in virtue of the fact that the example was earlier under discussion

[10] Each of these experimental methods will be detailed later [see Subsection: Psychological Time Models: Contrasting Perspectives]

[11] This important distinction between implicit (automatic) and explicit (controlled) information processing dates back to the pioneering works of Schneider, Shiffrin, Posner and Snyder, who laid down much of the groundwork of how attention and executive function interact to give rise to cognitive control (Schneider & Shiffrin, 1977a, 1977b; Posner & Snyder, 1975)

(i.e., was made explicit), it now has a temporal slot in memory, that allows for the retrieval (based largely on inferential reconstruction) of its pasthood (or pastness), the duration it occupied at the time, and the temporal relationship it had with other (encoded) activities conducted around the time of writing the example.

The role of dynamic memory: Dynamic memory, as conceived by Guyau (Michon, 1988) is simply the effective and adaptive utilization of the cognitive strategies that permit us to efficiently organize our knowledge representations of the world that surrounds us. At the time, little was known about the functional architecture of memory, but Michon (1988) identifies the following relationship that time has with dynamic memory: "Time is intrinsically connected with *dynamic memory*, that is, with the memory for concrete episodic events, localized in space, that together constitute a meaningful narrative, including the personal history that we recognize as our Self or Ego (p. 171)." Much progress since then has been made in the area of memory, especially concerning the neuronal underpinnings of the different components of memory. The basic distinction made in memory research with respect to memory-content is between declarative and non-declarative/procedural memory (Purves et al., 2004; Milner et al., 1998). Declarative memory (cf., explicit or controlled processing) is firstly propositional, which means its contents can be assigned a truth-value of either true or false. It represents a model of the external world that is accessible to consciousness, and allows for storage and retrieval of facts (viz., semantic memory), episodes (viz., episodic memory), and personal histories (viz., autobiographical memory). Common examples include the storage and subsequent retrieval of a sequence of digits (e.g., 4-3-1-2), or the recollection of a vacation you had in the summer of the year 2003. Non-declarative memory (cf. implicit or automatic processing) on the other hand is non-propositional, not readily available to conscious awareness and underlies changes in skilled behavior and associations. Typical examples are our ability to swing a tennis racket in response to a fast moving tennis ball, or the 'blind' dialling of a frequently dialled phone number.

Further, distinctions can be made about the temporal mode of memories - these include immediate memory, working memory, and long-term memory (Purves et al., 2004). Very briefly, immediate memory refers to the ability to hold the ongoing experiences (snapshot-like) comprising all our sensory modalities for fractions of a second. Working memory reflects the ability to hold information in our minds from the range of seconds-to-minutes (cf., the 'specious present'). Finally, long-term memory reflects our ability to retain information for days, weeks, or even a lifetime. Later, the foregoing distinctions in types and modes of memory will play a pertinent role in the present experimental investigation, as well as in the elaboration of the current models of psychological time [see Section: Psychological Time Models: Contrasting Perspectives and Section: Present Study].

2.3 The Plasticity of Subjective Time

The peculiar aspect of expansion and contraction of subjective time was already underscored during the 18th century by the Scottish philosopher Thomas Reid, who said:

> "When a man is racked with pain, or with expectation, he can hardly think of anything but his distress and the more his mind is occupied by that sole object, the longer the time appears. On the other hand, when he is entertained with cheerful music, with lively conversation and brisk sallies of wit, there seems to be the quickest succession of ideas, but the time appears shortest" (see Roeckelein, 2000, p. 28)

This curious phenomenon of the variability in the subjective flow of time is, from a cognitive standpoint, far from being the paragon of temporal experience (Michon, 1990). In fact, Michon (1996, 1990) stresses that duration is merely an abstract construction, a "derived and highly formal product of the mind (p. 38)." He argues that the psychophysical experimentation techniques that require people to compare time intervals, produce and reproduce them are a result of a language-dominated conventionalization process. Whether this is in fact true is a matter of furthering the current understanding on the causal relationship between language and thought (but see Kay & Regier, 2006 for an overview). Nevertheless, intuitively it is not immediately obvious how linguistic representations can inform human subjects that are, for example, being asked to psychophysically reproduce the duration of an event in a real-time novel experiment, especially since the method of reproduction does not require the (linguistic) translation of psychophysical responses given.

The point raised by Michon (1990) however is of valid importance when one considers the large repertoire of scripts or frames[12] that we possess (as adults). He notes that we enjoy a substantial number of "temporal standards for concrete, everyday 'natural' events, associated with scenarios... (p. 43)", and that alterations in our subjective flow of time can be more parsimoniously explained by deviations from the temporal expectations that a particular situation asks of our memory for time. At first glance, this would make sense precisely for 'everyday, concrete' experiences, but three problems may arise if this position is to be always taken seriously: first, it is generally difficult to test an ecologically-grounded hypothesis empirically. Second,if it were to be ecologically tested by, for example, asking people on a pedestrian street how long it would take to arrive at a familiar versus a vaguely-familiar destination, only verbal estimates are measured, which have been reported to be unreliable (Eisler, 1996; Block, 1990; Zakay, 1990). Finally, relying on a verbal estimate measure is necessarily linguistically-tainted, fulfilling Michon's (1990) ideas behind the language-dominated conventionalization process when it could be avoided by relying on psychophysical measures of duration estimates that do not require any translational processes (cf., method of reproduction (see Eisler, 1996)).

Michon (1996, 1990; 1990) has brought to question whether the automatic encoding of any temporal information is a necessary side effect of non-temporal information processing activities (see Block, 2003 for a different perspective on the automaticity of temporal information encoding). This essentially means that temporal information is by default mysteriously cloaked away unless explicitly attended to - in addition, the quality of the temporal representations constructed is suspect. By granting that temporal information is not automatically encoded, it is likely that time is constructed a posteriori (cf., Guyau's view that the conscious experience of time is derived from our cognitive processes),

[12]A script or a frame can be understood as an episodically concrete representation stored in memory of how an event or episode is 'supposed' to unfold under a particular context.

as a function of other cognitive activities - and while such constructions may not be entirely veridical (see Eisler, 1996), they do exhibit systematic durational effects under certain conditions (Grondin, 2001; Roeckelein, 2000; Block & Zakay, 1997; Hicks et al., 1976). Under the assumption that duration is a temporal attribute cognitively attached to events and event composites (see Jackson, 1990 for an in-depth coverage of this issue), can humans perceive empty time[13]?

From a theoretical vantage point, the differences between filled and empty durations was speculated on by James (1890), in the following thought experiment: May the reader turn away from reading this paragraph, close his/her eyes, and attend exclusively to the passage of time for a brief period of several seconds. If the contents of thought during this meditative activity are indeed lacking any material content, then it would mean that we have a sense for pure time and hence empty duration would serve as an adequate stimulus for psychological experimentation. On the other hand, if the contents of our thoughts are somehow occupied by something (e.g., reflection on the thought experiment itself), then the perception of empty time is illusory. According to James (1890), it is the latter that happens - empty duration is by necessity filled with some content from memory[14]. The explanation provided is that we are always aware of some change (whether it is our heart beats, the conscious reflection on what we are attending to, or a song that continually loops in our minds) - he writes:

> "Awareness of *change* is thus the condition on which our perception of time's flow depends; but there exists no reason to suppose that empty time's own changes are sufficient for the awareness of change to be aroused. The change must be of some concrete sort – an outward or inward sensible series, or a process of attention or volition" (p. 621).

By highlighting the importance of awareness[15] as a conditional requisite for the conscious perception of time flowing[16], James (1890) touched on a topic

[13]See Roeckelein, 2000, p. 120-135 and Paul Fraisse (1963) for an analysis of the methodological implications concerning the perception of filled and empty time, and how they differ experimentally. See also Lejeune (1996) for a discussion on experimentational procedures aimed at unveiling pure 'clock' time in humans and animals.

[14]This position can be contested by those who practice Zen meditation, who strongly claim that during a meditative trance, their thoughts are empty. However, just because one's thoughts are empty does not necessarily entail that one can attend to pure duration. Moreover, if duration is an (material) object that can be attended to, then those who meditate cannot be practicing Zen meditation, for their thoughts are not empty.

[15]It should be noted that one can make a solid distinction between awareness and attention. One can be aware of something, without necessarily attending to it. However, the converse is not true - in attending to something, one must necessarily be aware of it. Despite that it is possible to have awareness of something with explicitly attending to it, the partitioning is not entirely unambiguous - for the object of awareness can also be understood as an act of attending to that object, whether in the external world (on-line thinking) or in memory (off-line thinking). See also Lamme, 2003.

[16]Going against the grain, it remains unclear how the awareness of change comes about without any initial temporal grounding. Intuitively, 'change' requires that an object be already situated in time. If such intuitive suppositions are correct, this would suggest that time is of a dual-nature: time as a stream which is potentially accessible to conscious awareness (higher-level continuity), and time as a fundamental relation inherent in the transformation and positional delocalization of objects in space (lower-level continuity). Without such lower-level continuity, events and objects in the world would appear as discrete snapshots - even then, it is difficult to imagine how such discrete steps can be fathomed without invoking any temporal relationships that hold between the discontinuous snapshots. Theorizing of the sort

that would nourish most cognitive accounts of psychological time today - the role of attention (Block & Zakay, 2006; Tse et al., 2004; Brown & Boltz, 2002; Lejeune, 1998; Mattes & Ulrich, 1998; Block & Zakay, 1996; Macar et al., 1994; Zakay, 1992; Brown & Stubbs, 1992). By invoking attentional processes, the plastic character of the flow of time can be partially explained under particular contexts. For example, waiting for a friend who is late in picking you up makes you increasingly attend to time, and as a result the duration of the wait seems longer than what physical time dictates. In contrast, immersed in a gripping conversation with a good friend after two years of being away from each other makes the subjective flow of time accelerate beyond physical time - this is due to the disinterest with time during the engrossing conversation with the friend. James (1890), echoing Thomas Reid's insights about the lengthening and shortening of time, states:

> "*In general, a time filled with varied and interesting experiences seems short in passing, but long as we look back. On the other hand, a tract of time empty of experiences seems long in passing, but in retrospect short* (p. 624)."

James' (1890) observation surely brings to the forefront the plastic nature of time's flow; experimentally however, how can the subjective fluctuation of our flow of time be brought to the laboratory? By distinguishing 'time in passing' and 'time in retrospect', he disseminated the prerequisites for a substantial amount of cognitively-attired research that sought to test precisely this phenomenon - the lengthening and shortening of time under all sorts of experimental manipulations (Michon, 1990). These observations have led to the application of two methodologically influential paradigms by which the duration estimation literature falls under: the prospective paradigm and the retrospective paradigm (Zakay & Block, 1997; Block & Zakay, 1996; Block, 1990; Zakay, 1990); the former assesses experienced duration, whereby the person tested is aware that he/she will be asked to provide a duration estimate, while in the latter case, the person being tested is not aware that he/she will be asked to provide a duration estimate until after the to-be-judged target interval has passed. A detailed account of the differences between these paradigms and the experimental methods they utilize will be discussed later [see Section: Psychological Time Models: Contrasting Perspectives].

To briefly recapitulate the main ideas presented above, Jean-Marie Guyau believed that time itself is nowhere to be found in the universe, and is instead a cognitive manifestation arising out of the events we experience in our lives. Henri Bergson, on the other hand postulated that the so-called 'lived Duration' is a metaphysical entity that is no different than the essence of life - it was mentioned earlier that such a view does not have a place in any rigorous scientific account of psychological time, and was therefore left dismissed. Finally, William James in his highly influential work *The Principles of Psychology*, analyzed in detail our window of duration, what he referred to as the 'specious present', and extensively discussed the variability of our subjective flow of time, setting the stage for decades of experimental research that would later be labeled by Michon (1990, 1988) as the "age of the psychophysics of duration." Finally, it was proposed based on Michon's (1996, 1990) ideas that were themselves

can easily lead one to an impasse, and this strand of thought will be henceforth dismissed.

inspired by Guyau's views on time, that time is an abstract concept - a composite of mental representations, that derives from a basic, adaptive requirement to stay in harmony and flexibly deal with a dynamic and ever-transpirational world. The foregoing ideas, strongly representative of the views underlying this work, should be seen as the theoretical curtains by which subsequent considerations of psychological time stem from. After a brief introduction to the experimental study of time as duration, an in-depth analysis exposing the different models of psychological time (duration in particular) will be given.

3 Psychological Time Models: Contrasting Perspectives

3.1 Time as Duration

While the psychological time literature had chiefly witnessed a surge of psychophysical experimentation up until the late 80's, the 21^{st} century has been predominantly focused on the quest of unraveling the neural/biological substrates of psychological time. Such investigations have flourished primarily by probing into the molecular, cellular, and anatomical components (and their organizational dynamics), pathways and processes subserving our experience of time. The heightened recent interest into the neuropsychological and neuropharmacological mechanisms should be seen as complementary and not a substitute for research inquiring into the cognitive and behavioral aspects of our time experience - it is under this presumption that the remainder of the present work will fall under.

Richelle (1996) had likewise championed the foregoing when he raised the issue of how to reconcile the differing levels of complexity by which psychological time is exhibited. The underlying assumption is that a description at one level might pose a discontinuity with the other levels of complexity. Richelle (1996), in raising this fundamental problem concerning psychological time, brings to question the causal dependencies that exist at each level of complexity (e.g., whether biological (circadian) rhythms necessitate the acquisition of temporal regulation and timing estimates in humans and animals), and whether a sufficient understanding of a phenomenon can transcend such causal contingencies, given they do exist (cf., the independent yet constrained levels in Marr's (1982) levels of description and explanation). To simplify matters, whether a phenomenon should be studied independently and described at a particular level (discontinuity) or whether attempts should be undertaken at bringing the different levels of complexity and explanation under a unified conceptual framework (continuity) will be left open. Nevertheless, it is strongly believed that research into one level of complexity and explanation yields enough insight to sufficiently inform the other levels, if only to further unravel further constraint-webworks that are to be subsequently considered (but see Bechtel, 1994).

Block (1990) identified three broad constituents of psychological time: time as succession, time as temporal perspective, and time as duration. Time as succession reflects the sequential structure of events from which humans or animals perceive (or infer) succession and order. Research in this direction has generally attempted at uncovering the preconditions by which humans and animals can make judgments of simultaneity, temporal order, and event succession by invoking sensory and perceptual processes that permit such acts of judgment, preferably cast in biopsychological terms. Approaching the experience of time in this vein is of little interest to the present work, and will not be further unaccounted for (but see Patterson, 1990 and Roitblat & Young, 1990 for a good overview).

Time as temporal perspective (or temporal orientation) refers to the experiential and conceptual understanding and interpretation of the past, the present, and the future and how they vary across normal and pathological populations (Roeckelein, 2000; Block, 1990). Temporal perspectives as such can vary within an individual or across individuals, due to disease states (e.g., schizophrenia), pharmacologic interventions (e.g., administering dopaminergic and adrenargic agonists and antagonists), or due to cross-cultural variance (e.g., eastern versus western cultures). Bleeding into personality types, the attitude towards and relative importance placed on the past, present, or future can dramatically influence (if not partially determine) a person's day-to-day behavior especially with respect to the organization and (temporal-) planning of activities (see R. V. Levine, 1996 and Melges, 1990 for an in-depth discussion).

To provide a concrete everyday example, consider the conventionalized phenomenon of punctuality, a social contract that describes whether a person will make him/herself available at some place or engage in a particular activity if that person had proclaimed at an earlier time that he/she will do so. If a person values and is consciously aware of time, then that person will take precautionary measures to be punctual - this would involve walking to the desired end-point at a faster rate, the intermittent yet frequent checking of the (clock) time, and so on. Contrast this with a person who violates the requirement of punctuality - it can be said that this person has a different temporal perspective than the punctual person[17]. As will be discussed later, the importance of considering temporal perspective can provide powerful predictions in another aspect of psychological time - the perception and estimation of duration[18].

The last constituent of psychological time, time as duration, refers to the temporal (durational) attributes of events, the encoding and retention of such attributes, and their subsequent retrieval upon inquiry (Block, 1990). Duration timing, or time estimates[19] , is a an important ability that regulates and organizes much of our day-to-day activities especially when we execute an action and expect a response (Taatgen, Rijn, & Anderson, 2007; Block & Zakay, 1997). For example, consider a situation where one decides to drop by a friend's place unannounced, and rings the doorbell. How long must that person wait before deciding that the friend is not home (no response) and decides to leave?

Admittedly, the scenario highlighted above can not be explained by solely invoking timing mechanisms, since knowledge about the friend's general behavior (more specifically, temporal orientation) and overall circumstances that friend might be in (has he mentioned recently that he is going out often during the

[17]We do not wish to claim that temporal perspective is a consistent and rigid characteristic of people (although it could be under pathological states), but rather a symptom of particular circumstances that occur in a person's life.

[18]It should be evident that the use of such terminology is in fact misleading, since we do not believe one can directly perceive duration, but rather events. For simplicity, we will adhere to such terminological inadequacies, but the reader is cautioned in accepting such lax terminological usage.

[19]From here on, we will use 'duration estimates', 'time estimates', and 'duration judgments' interchangeably.

evenings?) fare equally into account (cf., reference memory and Michon's (1990) ideas about temporal behavior explained more parsimoniously by inspecting deviations from temporal expectations). Despite that duration timing behavior is interlaced with other aspects of cognition such as perception, learning decision-making (Taatgen et al., 2007) and theory of mind (Keysers & Gazzola, 2007; Leslie, Friedman, & German, 2004) which might also explain such an episode, it is clear that duration timing is an activity that enters many spheres of everyday activities, such as clicking on a weblink and experiencing longer than expected loading times - do you click on the link again and how long should you wait upon doing so, or do you simply decide that the server is down or that perhaps the link is broken and abandon the task at hand?

Researchers investigating time as durations, taking after James' (1890) observation between time in passing and time in retrospect, have posited two different paradigms by which (human) duration estimates can be experimentally probed: the prospective duration estimate paradigm, and the retrospective duration estimate paradigm[20] (Zakay & Block, 2004; Block & Zakay, 1997; Zakay & Block, 1997; Block, 1990).

By way of illustrating the differences between these two paradigms, reconsider the punctuality example mentioned earlier but from a different angle. Suppose that the person you are supposed to meet is late in arriving at the agreed upon meeting point. Assume also for the sake of argument that you do not possess a watch at the time, and there is no one around to ask for the clock time. The fact that you are waiting for the late friend and simultaneously conscious of the time passing (i.e., attending to time) regardless of other activities you happen to be engaged in then, if any, is representative of the prospective paradigm. In contrast, suppose that the two roles that you and the friend play are reversed - you now are the one that is late and the friend is impatiently waiting for you at the desired meeting point. Consider also that you were heavily preoccupied with some activity (e.g., talking on the phone to a girlfriend). Without any notion that you were late, you arrive half an hour late to the meeting, and the friend angrily asks if you have any notion of how long it took you to arrive at the meeting point. Reflecting on why you were late (e.g., you were talking on the phone, you then had to take the stairs to exit the apartment because the elevator wasn't working, etc.), you give the indignated friend a duration estimate based on (personal) events indexed in memory - such a scenario is representative of the retrospective duration estimate paradigm.

Three important aspects become clear upon a closer look at the aforementioned example illustrating the differences between prospective and retrospective duration estimates: first, prospective duration estimates are indicative of dual-processing cognitive behavior, the allocation of attention to temporal information (duration) itself, and attending to non-temporal information (Zakay & Block, 2004). Second, retrospective duration estimates rely on an inferential process that involves an active reconstruction of past events (or episodes), hence tightly coupled with our (episodic) memory system (Zakay & Block, 2004). Finally, given the outlined differences between two paradigms, it can be (initially) surmised that each paradigm is subserved by different cognitive processes. In fact, in a meta-analytic review of twenty experiments designed to test the two

[20] Hereforth the two duration estimate paradigms will be referred to as the prospective and retrospective paradigm, respectively.

paradigms, Block & Zakay, 1997 found that indeed, they do tap into different cognitive processes, in that prospective duration judgments are usually judged as longer and vary more than retrospective duration judgments (see also Zakay & Block, 2004).

From an experimental standpoint, the difference between the prospective and retrospective paradigms have been empirically tested by varying the instructions given to subjects: In a prospective paradigm, the experimenter informs the subject prior to testing that he/she will have to estimate the duration of a target interval presented after it has elapsed, while in a retrospective paradigm, the subject is given vague instructions about the aims of the experiment, and only after the target interval has elapsed, the subject (unaware that she will be asked to make a duration estimate) is then asked to estimate the duration of that interval (Zakay & Block, 2004; Block, 1990). The fundamental difference between the two paradigms led Block (1990) to refer to the prospective and retrospective temporal experiences as experienced and remembered duration, respectively. This terminological distinction reiterates the different aspects between the two paradigms: in a prospective paradigm, the subject is aware of the passage of time, and is hence experiencing such duration by allocating attentional resources to duration in real-time. By contrast, under the retrospective paradigm, the subject is unaware that he/she will be subsequently asked to judge duration, and is hence relying on memory constructs to retrieve the duration of the to-be-estimated interval.

The means by which to test the respective paradigms has been defined by four major methods (Zakay, 1990; Block, 1990):

1. *Verbal estimation:* After exposure to a target interval duration, the subject being tested is subsequently asked to provide a duration estimate verbally, subjectively expressed in seconds, minutes or hours.

2. *Duration production:* The subject is provided with a standard interval duration (stated verbally), and is subsequently asked to psychophysically delimit (produce) the given interval duration.

3. *Duration reproduction:* The subject is provided with a target interval that has to be later reproduced by means of some operation.

4. *Duration comparison:* A standard interval is given, and the subject is required to make an estimate by comparing the standard duration with the target duration (i.e., stating which interval is longer).

Each of the respective methods places further constraints on the kind of paradigm that can be employed (Block, 1990). For example, the methods of verbal estimation, comparison, or reproduction permit the testing of duration estimates under both prospective and retrospective paradigms. On the other hand, the method of production necessitates a prospective paradigm, since the subject has to know prior to testing what the target interval to be later produced is. The choice of method may also bring to question what kind of processes each taps into (Zakay, 1990) - for example, the methods of verbal estimates and production (where an initial duration is reported verbally) require subjects to translate the standard durations into conventional units. Intuitively, the verbal estimation method can never be fully reliable as it consistently elicits the tendency to round off time units (e.g., 2s, 2.5s, 3s, etc.). In order to free duration estimates from contaminating variables, it seems that the methods of comparison and reproduction are an ideal choice - nevertheless, it might be undesirable to employ the comparison method if one wants to eliminate any bias that might result from initially presenting a standard of a particular duration; in other words, straying away from relative duration judgments and opting for absolute duration judgments (see Zakay, 1990 for an in-depth discussion of the different methods and what they entail).

As any time researcher might come to know, there is an explosive number of factors that should be controlled for when experimentally testing for psychological time, over and beyond working under a specific model. Block (1990) provides a descriptive, general 'contextualistic' framework comprising four salient factors that exert influences on psychological time:

1. *Characteristics of the time experiencer:* Certain characteristics of the time experiencer include variable such as sex, species, personality type, temporal orientation, interests, and past experiences.

2. *The contents of a temporal period:* Contents of a time period surface certain features of events and event composites, such as number, complexity, modality-type, novelty, duration, and motion.

3. *Activities performed within the temporal period:* These activities can range from passive viewing of external events, to strategic and deliberate (active) processing of events.

4. *Temporal behaviors and judgments:* The experiment might require of subjects to perform particular kinds of time-related behaviors, such as judging simultaneity and successiveness, rhythmic motor activity, judgments of order and spacing, duration estimates, stimulus discrimination based on temporal manipulations, and so on.

The aforesaid factors, while by no means exhaustive, do provide general guidelines that serve to narrow down the focus of psychological time experimentation. Block (1990) raised the issue that an alteration in the parameters of one of the factors can have a significant influence on the other factors - notwithstanding such cautionary measures, it is difficult to account for each and every factor, especially since experimental predictions usually concern one or two factors at most. By attempting to control for all factors, one might put the interpretability of results obtained at risk. Nevertheless, the message to be taken is that is extremely difficult, if not downright impossible, to divorce the experimental study of psychological time from its measurement, an issue eloquently expressed by Zakay (1990) when he stated that subjective time is "an entity that, like the path of the atom's elementary particles, is not separable from its measurement" (p. 60).

Earlier, in illustrating the differences between the prospective and retrospective paradigms, it was pointed out that these two paradigms may in fact draw on different cognitive resources and tap into different cognitive processes. More specifically, it was shown that in a prospective paradigm, a person is experiencing duration insofar that he/she is allocating attentional resources to time, and that in a retrospective paradigm, duration estimates are largely the conscious product of retrieving past events from memory, be it working memory or long-term memory. Past studies have accumulated several strands of evidence that support the idea that the prospective paradigm draws primarily on attentional resources (Zakay & Block, 2004; Brown & Boltz, 2002; Mattes & Ulrich, 1998; Macar et al., 1994; Brown & Stubbs, 1992; Brown, 1985), and that the retrospective paradigm draws on inferential abilities and resources from memory (Zakay & Block, 2004; Block & Zakay, 1997; Hicks et al., 1976; Ornstein, 1969). However, the partitioning between the two paradigms, and how to plausibly and parsimoniously expound the cognitive processes involved in each is far from definitive.

As a result, several attempts at formal models of psychological time have been proposed, ranging from chronobiological models that seek to explain circadian activity over the span of hours, attentional models that emphasize the role of attentional mechanisms in our perception of time, models that delineate the complex role of memory in understanding the passage of time, neural models that explain timing via neural network state activity, to models that posit some kind of internal biological clock that serves as a time-keeping device. Block (2003; 1996) proposed a useful distinction aimed at demarcating and conveniently characterizing the different class of models: timing-with-a-timer models and timing-without-a-timer models.

The timer-based models can be understood as subsuming chronobiological models and models that postulate some inner clock, and timer-less models as subsuming attentional, memory-based, and network state models. In a nutshell, the timer-based models presume that humans (as well as animals) bear a pacemaker mechanism, that subserves our psychological time system (Block & Zakay, 1996). In contrast, timer-less models propose that psychological time is constructed from general-purpose information processing activities - essentially a by-product of our cognitive processing (cf., Guyau's view that psychological time is a by-product of our experiences with the world).

The choice of which model to adopt in doing time research raises key questions about the validity, robustness, parsimoniousness, and generalizability of the formal model in question: Can we arrive at a *general* model of psychological time? Can the model be generalized to account for timing behavior in different primate species? Given that there is an internal clock, or internal clocks, what kinds of constraints do they require of cognitive-level descriptions of psychological time? Would models that explain interval timing in the range of milliseconds also explain timing behavior in the range of seconds-to-minutes and vice versa? What of circadian activity spanning hours and days? Is the model able to make predictions about the different paradigms involved (prospective and retrospective)? Is the model described in sufficient detail so as to be (potentially) falsifiable? Can the model provide enough explanatory power to sufficiently inform the different levels of discourse (cf., Marr's (1982) levels of explanation)? Will the model be capable of accounting for the immense amount of experimental evidence gathered since the inception of the experimental study of psychological time? Finally, is the model parsimonious?

It is questions of this sort, emphasizing the difficulty in arriving at a unificatory model of psychological time, that led Block (1990) a little less than two decades ago to enunciate that "No existing model can handle the variety of experimental evidence on psychological time" (p. 1). Below, we consider some of the models that have a played a significant role in advancing research in the psychology of time, especially from a cognitive standpoint.

3.2 Models of Psychological Time

3.2.1 Clock Models

Overview of Clock-Models The idea of an internal clock that functions as an event-independent timer dates back to the work of Haugland (1934; 1933). He posited that temporal behaviors and judgments are subserved by chemical processes in the brain, a mechanism clear of any exogenous influences that he referred to as the *master chemical clock*. This chemical clock was meant to account for timing behaviors for brief periods, as well as account for physiological factors such as fluctuations in body temperature (Hoagland & Reiser, 1934). Haugland's idea about a chemical clock later lead Treisman (1963) to propose the internal clock model, without further speculating on the neuronal underpinnings of the clock. Very briefly, the model consists of five main components: A pacemaker, a counter, a comparator, a memory store, and a mechanism that outputs a verbal time estimate. The pacemaker autonomously produces a series of pulses, that can be influenced by specific (exogenous factors) and general arousal (internal to the organism, cf., circadian rhythms) levels of an organism. The pulses accumulate in a counter, that records the numer of pulses at a given time, which are then transmitted to the memory store and the comparator. Finally the verbal output mechanism retrieves a duration estimate through the comparison of pulses in the comparator and the memory store. This model, despite its simplicity, inaugurated an entire school of thought in search of the localization and understanding of an internal clock device - a device that we share with other non-human primates that explains most, if not all, our interval timing behavior.

Researchers (comprising mainly behavioral psychologists) working under the assumption that humans and animals posssess an internal clock, have idiosyncratically concerned themselves with non-human animals, such as pigeons or rats. Recently however, several attempts have been made to generalize the animal timing models to humans (Wearden, 2003; Allan, 1998). One such important temporal information processing model, proposed by Gibbon, Church, and Meck (1984) to account for animal temporal behavior, is the scalar timing model, essentially a psychophysical model of psychological time[21]. This model was initially developed to account for the behavioral regularities that rats and pigeons exhibited under classical "temporally constrained" reinforcement schedules, as well as unique tasks such as bisection and temporal generalization that were developed specifically to test the strength of the model. The scalar timing model was quite successful in accounting for timing data gathered from animals, and this eventually lead researchers to consider applying the model to humans (Wearden, 2003). Given the popular and widespread acceptance of the scalar timing model, a detailed yet non-technical examination of its central tenets is warranted. First, a brief overview of chronobiological models will be given.

[21]Note the close linkage between scalar timing models, which account for psychological time, and *scalar expectancy theory*, which is an associative learning model that accounts for learning behavior in general (Block, 2003)

Chronobiological Models It is apparent that much of our everyday behavior is cyclic - we usually have breakfast, lunch, and dinner at designated times each day and from one day to the next, we go through fairly consistent sleep-wake cycles. Exogenously, the seasons change, and our bodies (even independent of seasonal temperature under certain conditions) adjust the internal temperature accordingly (a biological process known as homeostasis) (Perreau-Lenz, Pévet, Buijs, & Kalsbeek, 2004). More so, cyclic behavior is relatively robust in affording humans a temporal frame of reference, notwithstanding changes in the external environment and internal biological changes in our physiological and cognitive lives (Block, 1990). The field of chronobiology, in brief, attempts to unravel the complex relationships between endogenous biological rhythms and overt cyclical behavior comprising states of activity (energy consumption and exertion), homeostasis, as well as feeding, mating, and sleeping behavior. What, however, controls such cyclic behavior? The approach undertaken by chronobiologists studying cyclical behavior has been to posit some circadian pacemaker or oscillator (viz., a circadian clock), whereby the time-keeping functions of this clock regulate and structure our behavior (Block, 1990).

Over the years, the idea that humans (as well as primates) have some circadian clock that regulates cyclical behavior has been largely confirmed, driving research into further unraveling the molecular mechanisms of the circadian clock (Antle & Silver, 2005; Perreau-Lenz et al., 2004; Kuriyama et al., 2003). The circadian clock has been located in the suprachiasmatic nuclei (SCN), a set of structures contained within the anterior hypothalamus, a site responsible for (circadian) control of homeostasis functions (Purves et al., 2004). The established reality of the circadian clock has lead researchers to consider how circadian fluctuations influences our subjective passage of time - indeed, the major finding was that people who were isolated from exogenous factors (daylight, clocks, etc.), tended to verbally underestimate the passage of time (see Campbell, 1990; Block, 1990 for an in-depth coverage).

For the present work, the details of circadian clock models are of secondary interest. Nevertheless, the variability in duration estimates exhibited when circadian parameters have been manipulated highlights an important aspect of our temporal experience and our cognition - the fact that we are necessarily bound by circadian rules, despite their lack of stringency. More over, this relates to the earlier discussions on temporal perspective (how individuals understand and act towards the past, present, and future). A disruption in circadian activity (e.g., jet lag) can leave a person temporally disoriented, as a result affecting his/her cognitive activity (see Dawson, 2004 and Esposito et al., 2007) - by disrupting cognitive activity, it becomes clear that circadian activity can, by transitive consequence, impact other aspects of psychological time, such as experimentally probed duration estimates.

Further, it is surmised here that pharmacologic-induced alterations to our brain chemistry, likewise disrupt the normal (baseline) functioning of the circadian clock. While this intuitive fact may appear trivial, it is surprising that most research has been primarily focused on the effects of pharmacological interventions (e.g., administration of psilocybin, a serotonergic receptor agonist, or ketamine, an NMDA receptor antagonist) on interval timing (Ruey-Kuang Cheng, 2006; Wittmann et al., 2007); or more broadly the properties of an internal clock (an interval-timing structure) (Meck, 2006, 1996), without consideration of how alterations to the circadian clock can exert influences on interval timing behavior in the first place. This essentially involves a deeper understanding of the causal dependencies between circadian rhythms and speculated internal clocks controlling for relatively short timing intervals, and determining the direction(s) of this causal arrow.

Scalar-Timing Model As mentioned earlier, the scalar-timing model is a mathematical model that attempts at formally describing and fleshing out the cognitive processes at play when an organism is confronted with an interval-timing task (Allan, 1998). Prior to providing the basic components and their respective interaction in the scalar-timing model, an important theoretical point underscored by Wearden (2003) warrants mentioning: What does it mean to say that a particular behavior conforms or does not conform to the scalar-timing model?

Wearden (2003) asserts that two requirements have to be met by the scalar-timing model to ensure that an adequate explanation of timing behavior is met: the mean accuracy requirement and the scalar property. The first of these requires that the provided subjective estimates of some physical duration are on average accurate approximations of physical duration. Second, the gathered data should exhibit the scalar property. This is the same as Weber's law, but applied to timing behavior; it states the following: the standard deviation of subjective duration judgments increases as a linear function of mean duration judgments given (Allan, 1998). Another way of tapping into this property is by seeing that the coefficient of variation (standard deviation divided by mean duration judgments) remains constant despite variability in the target interval to be estimated.

The scalar-timing model, in its bare bones, embodies a tri-partite configuration (Wearden, 2003; Allan, 1998) with three essential information-processing levels: a clock (timing) system, a memory (storage) system, and a decision-making (response) system (see Figure 1). The clock system, responsible for the transformation of physical duration into subjective duration, consists of three components: a pacemaker, a switch, and an accumulator. The pacemaker emits pulses at a mean rate, that are sent to the accumulator given that a timing interval is to be timed (switch opening). The accumulator adds up the emitted pulses, and grows as a linear function of physical time. This growth is measured by considering that the psychophysical law for time is a power function with a constant exponent of 1.0. The memory system consists of two separate components: a working memory buffer and a reference memory buffer. The current contents of the accumulator are sent to and stored in the working memory buffer, which are also transferred to the reference memory buffer. The reference memory buffer maintains a history register of durations over past trials. The contents of each of the memory buffers are then compared at the decision-level, via a comparator mechanism that compares the current trial time with the remembered time from the reference memory. After the comparison, a response is made (see Figure 1).

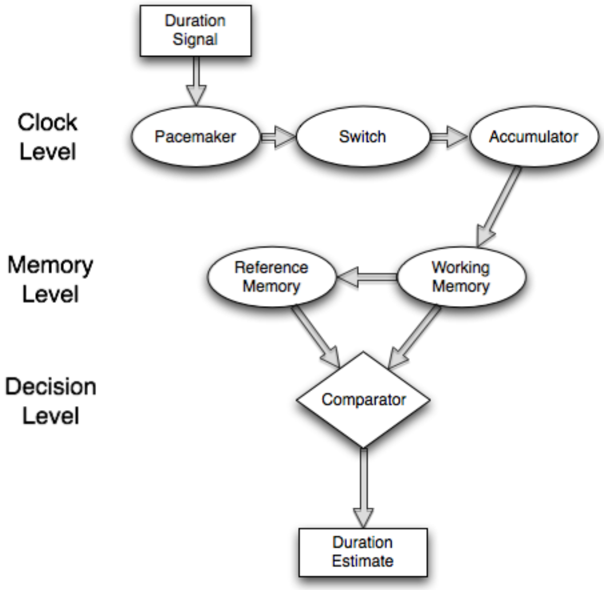

Figure 1: The scalar timing model: a schematic representation. (Based on Allan, 1998.)

As a model of interval-timing behavior that was initially developed to account for animal timing behavior and later extended to accommodate human timing, it has its merits and limitations (Wearden, 2003). The most important highlight of such a model is that it provides a coherent, quantitative model, that can be used to mathematically predict timing behavior, especially in animals. Another important feature is that it has provided empirical support for the notion that animals and humans possess an internal clock that regulates and serves as a time-keeping device for timing behavior.

There are three major limitations that Wearden (2003) mentions: first, it is difficult to bridge such a model to account for cognitively-oriented timing behavior that invokes attentional processes. Second, the idea of an internal clock has been brought into question with concern over the biological realizability of the model (Buhusi & Meck, 2005). Finally, the model has difficulty in accounting for timing tasks that require the verbal estimation, production, comparison, and reproduction of duration intervals. Notwithstanding its merits as a mathematical model that can provide solid prediction of timing behavior, two major limitations leave the model unsuitable to account for human timing: the neglect of attentional processes, and the postulation of an internal clock. Each of these limitations have a suitable alternative, and will be considered below.

Attentional-Gate Model Given the limitations on the scalar-timing model, Block and Zakay (2006); Zakay and Block (1997); Block and Zakay (1996); Block (1990) have proposed an alternative model that incorporates the basic tenets of the scalar timing model, with the additional component of an attentional module that is deemed to be more characteristic of how humans process temporal information (in specific, interval timing). Block (2003) highlights a number of limitations of the scalar-timing model, that provide sufficient justification for positing the attentional-gate model as explanatorily more powerful than the scalar-timing model.

First, as mentioned by Wearden (2003), the pacemaker (part of the clock system) has not yet been localized in the brain, which poses limits on the implementational requirement of such a model (cf., Marr's (1982) implementational requirement). Second, as also expressed by Wearden (2003), scalar-timing models have gained empirical support from relatively few paradigms, namely, the peak-procedure and the temporal bisection task, with almost complete disregard for the paradigms that arose out of cognitive psychology (production, verbal estimation, and reproduction of duration). Third, scalar-timing models have relied primarily on the timing and estimation of empty events, where the animal has to estimate a single stimulus or the interval between the provision of one stimulus and a reinforcer, or vice versa. On the other hand, timing in humans takes its primary focus the estimation of the duration of filled events, with greater focus on the cognitive factors (e.g., attention, memory) and less on the behavioral aspects of timing behavior (e.g., reward anticipation, stimulus reinforcement).

Fourth, as already stated, scalar-timing models do not account for attentional processes, which leaves a wide explanatory gap between animal and human timing behavior. Fifth, the scalar-property in scalar-timing models does not appear to be unique to time. Finally, the assumption that subjective duration scales linearly with physical duration does not seem to be widely supported, as some others have shown that the power function requires an exponent of 0.9, and not 1.0. Admittedly, not all the limitations highlighted by Block (2003) provide strong counter-arguments for the dismissal of scalar-timing model; nevertheless, some of the limitations do have force, such as the dismissal of attentional processes, the lack of empirical support in human timing studies, and the lack of biological realizability.

The attentional-gate model posits that humans (and probably our close non-human relatives) have two processors, a temporal information processor and a non-temporal information processor, in which attentional processes (and executive functions in general) function as modulators. Like the scalar-timing model, the attentional-gate model (Block & Zakay, 2006, 1996) involves a clock system, a memory system, a decision system, with the addition of an attentional system (see Figure 2). The model works as follows: a pacemaker emits pulses at a constant rate, but with the possibility of increased and decreased in the pulse emission rate given alterations in the organism's arousal level. The signals are then passed through the attentional gate, which is continuously guided by executive processes that open or close the gate in a graded fashion. In other words, the more attentional resources deployed for temporal information, the wider the gate opens[22], and vice versa.

[22]It has been brought into question whether requirement of an attentional gate is necessary to explain timing behavior, instead of only adjustment to the behavior of the switch (but see Lejeune (1998) and Zakay (2000) for a reply, and Lejeune (2000) for a response to Zakay's reply).

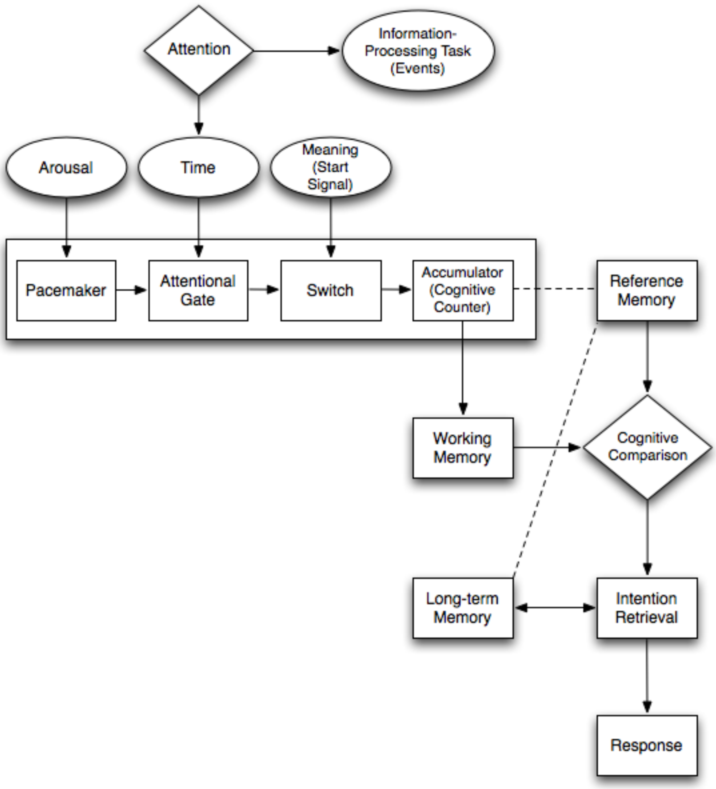

Figure 2: The attentional-gate model. (From Block & Zakay, 2006. Adapted by permission.)

Next, the switch opens or closes depending on the onset and offset of the target interval to be encoded; if the subject decides to begin encoding a target interval, the switch opens, and when the target interval has elapsed, the switch closes, thereby disallowing the further accumulation of pulses in the accumulator. The accumulator component collects the signals of interest and transfers them to the working memory buffer. Two different processes can happen at this stage: either the duration of the target interval is retrieved from long-term memory, which is then transferred to the reference memory buffer for later comparison, or the collected pulses in working memory are directly sent to the reference memory buffer. This depends on the method of estimation employed [see Subsection: Time as Duration] in a respective timing task. For example, if a subject has to *produce* a (relatively long) target interval, then the duration of the interval to be *produced* would be retrieved from long-term memory. In contrast, if the duration of an event has to be *reproduced* immediately after the elapse of the target interval, then the pulses are compared directly from working memory. After a comparison is complete, the intention retrieval module, as the name suggests, retrieves the intention to mark off the duration of an interval, upon which a response is then made.

The attentional-gate model, by providing a systematic and plausible account (with empirical support; e.g., Zakay & Block, 2004) of the processes that underlie timing behavior, appears to deal with many of the shortcomings of the scalar-timing model. However, it is not without problems: while it provides an account at the information-processing level, its neuronal underpinnings appear to be as of yet lacking, especially since it also posits the existence of a clock-like system. An alternative model, functionally isomorphic to the attentional-gate model, yet dismisses the idea of a clock is proposed by Block and Zakay (1996), and will be considered in the next section (see also Block, 2003).

3.2.2 Clock-Free Models

Storage-Size Model Perhaps one of the first (plausible) models developed that does not assume an internal clock mechanism responsible for interval-timing is Ornstein's (1969) storage-size model. He argued that a more parsimonious approach to duration retention and retrieval is to appeal solely to memory processes, where the recalled duration is a function of the amount of information processed (see (Hicks et al., 1976) for empirical evidence). The kinds of information that can affect subsequent event durations is dependent on factors such as the amount of stimuli processed, the kinds of strategies employed in encoding such stimuli (e.g., stimulus complexity), and so on. For example, if more stimuli are processed, then there would be a greater number of events indexed in memory, and hence subsequent duration estimates will be longer than if a fewer number of stimuli were encoded.

Despite that the storage-size model gained empirical support, Block (1990) argues that it is not the processing of the properties of stimuli in the world per se that account for longer duration estimates, but rather the interaction between the individual and the world. In other words, it is the inter-variability in how an individual encodes the stimuli that give rise to longer durations, and not due to the intrinsic features of stimuli. By means of an example, they argue that it is not because a sequence of stimuli is complex that gives rise to greater recalled duration, it is rather due to the wider interpretations that accompany the processing of a more complex sequence of stimuli. With respect to the storage-size model, this analysis does surface a weakness in the model, since it is not solely the storage slots in memory that account for the variability in duration estimates, but rather the memories of the efforts (or processing strategies) required to encode certain stimuli. Nevertheless, the proposed distinction does not undermine the fact that complex stimuli give rise to longer duration estimates, but rather brings to question the hypothesized underlying cognitive processes responsible for such variability in duration estimates.

Contextual-Change Model Given the limitations of Ornstein's (1969) storage-size model in explaining how the cognitive processes involved in duration estimates yield longer duration estimates for complex stimuli, Block and Zakay (1996) and Block (1990) proposed an alternative model: the contextual-change model. In this model, the kind of information that molds subjective time is "varied contextual associations, which may serve as time-tags" (Block & Zakay, 1996, p. 185). Under this hypothesis, it is the encoding of contextual information that gives rise to differing cognitive contexts, whereby duration intervals are retrieved on the basis of changes in such contexts; that is to say, subjects base their duration judgments on the amount of contextual changes available in memory, that serve as time tags for subsequent duration retrieval.

While this model was originally developed to account for retrospective duration judgments, where attentional processes are disregarded since the subject is not aware during the target interval that she/he will be asked to attend to time, it is functionally isomorphic to the attentional-gate model (Block & Zakay, 1996), minus the assumption of an internal clock. Under a prospective paradigm, the components of the attentional-gate model translate into the following: the pacemaker becomes a context-generator, the pulse accumulator becomes the context recorder, and the comparison module now compares contexts rather than collected pulses. The difference in this model, Block and Zakay (1996) note, is that unlike the attentional-gate model which assumes a periodic emission of pulses, the generated contexts are produced on the basis of different kinds of information that are processed at a given period.

Under a retrospective paradigm however, the model assumes that individuals do not assign time tags to salient contextual information, but rather rely on the retrieval of contextual information associated with events, such as the emotional, environmental, and encoding strategies associated with these event-contexts. For retrospective judgments, the model differs than its prospective counterpart in the following ways: first, the switch component is absent, since the subject does not know that the events he or she witnesses have to be timed. Second, the generated contexts are assumed to be stored in long-term episodic memory, and when later duration judgments are asked of subjects, they compare their initially stored event-memories with their current reconstructions (based on the amount of contextual changes) of the past events.

The contextual-change model has immediate benefits insofar as it does not require the existence of an internal clock, a device that lacks biological support. However, while the model seems to offer a parsimonious alternative to the attentional-gate model, it leaves some important questions lurking in the background: What exactly gives rise to these cognitive contextual changes? What are the determinants of environmental (stimuli) saliency? Are there features of interactions between individuals and their encoding of stimuli that are common to the extent of universality? For example, consider how some people are more attentive to details than others. Moreover, can saliency of certain contexts to be later retrieved be shared amongst different subjects? In other words, salient features of stimuli appear to be subjective to the extent that people may differ in their beliefs about what constitutes saliency. Notwithstanding these ambiguities, the model does provide a plausible account of how duration estimates are retrieved - what remains is to elucidate what gives rises to varied contextual associations that are later retrieved in the first place.

Coincidence-Detection Model Over the recent years, neuroscience has made immense progress in attempts at localizing cognitive phenomena at the brain level. This had lead many researchers to question whether our temporal experiences are subserved by unique (modular) brain structures or are a result of distributed brain activity responsible for other non-temporal cognitive processing (Ivry & Schlerf, 2008; Karmarkar & Buonomano, 2007; Buhusi & Meck, 2005; Ivry & Spencer, 2004; Meck & Malapani, 2004; Rao, Mayer, & Harrington, 2001; Matell & Meck, 2000).

Ivry and Schlerf (2008) made a distinction between what they call dedicated models of time perception, and intrinsic models of time perception. Like other cognitive phenomena, dedicated models surface the notion of modularity - that is, whether our temporal experiences are the consequence of a specialized time-keeping structure indicative of a clock-like neural mechanism. By analogy, just like it has been shown that certain neural structures code for color, it could be that there exists a specialized structure that codes for time. Intrinsic models, by contrast, entertain the possibility that duration is coded as a ubiquitous and intrinsic property of dynamic brain activity. Whether time is coded via a specialized structure or the result of state-dependent brain activity, there is little question that some biological mechanism accounts for the plasticity of subjective time; this idea has been heavily nourished through the observation that particular pharmacologic agents and types of brain damage can lead to drastic variations in the acceleration and deceleration of subjective time (Wittman & Paulus, 2007; Meck, 1996).

One particularly appealing model that seeks to explain interval-timing behavior in the seconds-to-minutes range is the coincidence-detection model (Buhusi & Meck, 2005; Matell & Meck, 2000). To illustrate its basic functioning, Buhusi and Meck (2005) draw an analogy with how a Global Positioning System (GPS) works: a GPS system is able to provide the current position "by triangulating temporal information (the difference or coincidence in phase of signals) from satellites" (p.755). Just like a GPS system is able, via coincidental detection of signals, to identify the current position, so can interval-timing be constructed from the coincidental activation of different neuronal populations distributed over the brain. Under this biologically-inspired theory, the basal ganglia serve to monitor the patterned activity of the thalamo-cortico-striatal circuit; in other words, the basal ganglia function as coincidence-detectors of brain activity that are relayed to working memory, which account for foraging behavior, conscious time estimation, and temporally-constrained decision making (Buhusi & Meck, 2005). While the details of this model is beyond the scope of this work, the model itself appears to be not only a plausible alternative to clock models, but also meets the biological requirements for realizability at the level of the brain (cf., Marr's (1982) implementational level).

4 Present Study

The present study is concerned with how different experimental factors affect the acceleration or deceleration of the passage of time. In specific, the experiment manipulates the effects of stimulus complexity, stimulus quantity, and the influence of higher-order cognitive interference on reproduced duration estimates under both the retrospective and prospective paradigm. Reasons for testing both paradigms is because the retrospective paradigm is limited to a single trial (Zakay, 1990), which means a large number of subjects is required. By controlling for the first trial of the experiment, claims can be made about the retrospective paradigm - after the first trial, the task necessarily becomes prospective.

Zakay (1990) provided several precautionary measures in conducting psychological time experiments, one of which concerns the validity of incompatible designs. He argues that a design should be internally compatible to avoid any confounding factors - for example, by testing either short-term memory processes or long-term memory processes, consistently attracting subjects' attention towards the passage of time or consistently detracting their attention away from the passage of time. Implicitly, this means that including both the retrospective paradigm and prospective paradigm under a single experimental umbrella might pose undesirable confounds in the results, since the retrospective paradigm relies on long-term memory processes for event-duration retrieval, while the prospective paradigm *generally* relies on working memory[23] processes. For the present study, this problem is avoided for two reasons: only one duration estimate method is used, the method of reproduction, which is compatible with both paradigms (Block, 1990). With respect to memory processes, the current design tests duration reproductions from long-term memory, given the long target interval to be reproduced, which has a physical duration of 12000 ms (Block & Zakay, 2006; Ulbrich, Churan, Fink, & Wittmann, 2006). This will be elaborated on below.

As mentioned previously [see Section: History of Time in Cognitive Psychology], Guyau had anticipated the important role that properties of stimuli play in shaping our experience of time (Roeckelein, 2000). He listed a number of factors, including stimuli magnitude, stimuli quantity, the amount of attention deployed to stimuli, the differences between stimuli, and the expectations raised by stimuli. Furthermore, James (1890) had underscored the importance of the perceptual features of stimuli and how they contribute to our subjective experience of time. Two of these characteristics are of particular relevance to the present work: the differences between stimuli and the quantity of stimuli.

In order to test how different stimuli affect our experience of time, the complexity of stimuli was controlled for in the first hypothesis: Under a prospective paradigm, the duration of complex stimulus events will be reproduced as shorter than the duration of simple stimulus events, since complex stimuli would take up more attentional resources - as a result subjects attend less to time (under the tenets of the attentional-gate model). Under a retrospective paradigm, the duration of the complex stimulus events will be reproduced as longer than simple stimuli events, since the former provides greater saliency in memory, accounting for greater event constructions from memory (cf, Ornstein's (1969) storage-size model). This issue was already speculated on by Block and Zakay (1997), who found that stimulus complexity was an important moderator variable in psychological time experiments, with respect to the retrospective paradigm only. The finding was that the greater the stimulus complexity, the greater the remembered duration - this, as they mention, can be explained by the contextual-change model (Block & Zakay, 1996); given that complex stimuli are open to a wider range of interpretations accounts for an increased number of cognitive contextual changes. This was verified however, only if subjects were actively processing the stimuli. With respect to the prospective paradigm, Block and Zakay (1997) found that complexity did not influence duration estimates. This unexpected finding warrants further investigation, and is examined under the current hypothesis.

The foregoing discussion of stimulus complexity ties in neatly with research concerning visual working memory and its capacity for types of visual items. Eng, Chen, and Jiang (2005) found that the visual working memory capacity decreased for complex stimuli - however, this was no longer true if subjects were

[23]Also known as Short-term Memory (STM), although some researchers make a solid distinction between the two - here, we will use the terms synonymously.

allowed to view stimuli for a longer period. This suggests that while perceptual complexity may partially determine visual working memory capacity only if there are no encoding limitations (i.e., viewing time of complex stimuli), providing further support for a similar finding by Alvarez and Cavanagh (2004). Luck and Vogel (1997), in examining visual working memory storage capacity for stimuli features and conjunctions of features, found that it is possible to retain only four color or orientation stimulus features at a time; however, they also found that it is possible to retain orientation as well as color of four different objects. This suggests that visual working memory "stores integrated objects rather than individual features (p. 279)." Finally, in a recent study, Awh, Barton, and Vogel (2007) found that the number of items in visual working memory is fixed to around four items irrespective of complexity, a finding that contradicts those of Eng et al. (2005) and Alvarez and Cavanagh (2004). Notwithstanding the aforementioned studies concerning visual working memory capacity, their complex stimuli drastically differ than the stimuli employed in this study - they consisted primarily of color blobs, letters, polygons, squiggles, cubes and faces, none of which resemble the commonsense, everyday objects used here [see Subsection: Apparatus & Stimuli].

Complexity of stimuli and subjective time were investigated by Macar et al. (1994) where he found that stimulus complexity generally results in a shortening of duration reproductions; this is in line with attentional models of psychological time. However, their complex stimuli were restricted to words or sets of letters, where the present concern is with visual complexity. Visual complexity here is narrowly defined as multi-dimensional variation in stimulus size, position, color, and background pattern. This ties in with Fetterman's (1996) thorough analysis of stimuli complexity, and the effect complexity has on psychological research. Adopting a Gibsonian approach, he argues that for timing research, like other perceptual domains, the stimuli should be sufficiently complex, fulfilling an adequate approximation of stimuli in the real-world. He raises a crucial point regarding complexity: complexity in the eyes of the experimenter might be a natural identification with the real world for the human or animal subject, whereby simple (or impoverished) stimuli are in fact more difficult to interpret. For the present work, it is difficult to imagine how any of the commonsense objects displayed on screen can be difficult to interpret [see Subsection: Apparatus & Stimuli].

The second manipulation tested in this experiment was varying the quantity of stimuli, while keeping the physical duration constant. Predebon (1996a, 1996b) found that increasing the quantity of stimuli while keeping the physical duration constant for long intervals (60 s) resulted in (via magnitude estimation as well as reproduction) a decrease in prospective duration judgments, but an increase in retrospective duration judgments. The former effect however was evident only when subjects were required to give overt responses (active processing), while the latter effect was exhibited regardless of processing type. Macar (1996), on the other hand, found that smaller quantities of stimuli resulted in short prospective duration reproductions. The variability in constructing experimental setups and the variegated choice of duration estimate methods (see e.g., Eisler, 1996; Zakay, 1990) could be a valid reason that accounts for the discrepancy between Predebon's (1996a, 1996b) and Macar's (1996) findings; nevertheless, the findings provide a discrepancy that is worth clarifying. Moreover, in their experimental meta-analytic review, Block and Zakay (1997) found that the quantity of stimuli is also an important moderator variable that requires further explication.

Intuitively, stimulus quantity appears to play a notable role in molding our experience of time. With respect to stimulus quantity, the following hypotheses were postulated: Under both prospective and retrospective paradigms, increasing the quantity of stimuli while keeping physical duration constant should result in greater duration reproductions than when presenting fewer stimuli with the same physical duration, in so far as the concurrent non-temporal task is not too difficult (i.e., not highly attention demanding), and there is sufficient time to encode the stimuli. Despite that the hypothesis is at odds with Predebon's (1996b, 1996a) finding, the reasoning behind this is as follows: Despite that many stimuli might consume more attentional resources, upon reproducing duration, the subject has more events indexed in (long-term) memory, and as a result will reproduce the duration of the target interval as longer than if there were few stimuli with an identical physical duration. However, as noted earlier, this is highly contingent on the attentional processing demands posed by the non-temporal task to be performed prospectively.

The last manipulation considered in the present study questions the effect of higher order cognitive interference on duration reproductions. This manipulation was investigated by Martínez (1994), in order to reveal how immediate reproduced prospective judgments compare to remote (delayed) reproduced duration judgments, when a (verbal) preparatory secondary task is presented in between. The finding of interest in the study is that prospective reproductions made after a verbal (structural, semantic, or mixed) recognition task (i.e., the preparatory secondary task) tended to be more accurate (i.e., an increase in duration reproductions) than reproduction judgments made immediately upon termination of the event interval to be estimated, despite that all reproductions tended to be underestimates of the target interval. Martínez (1994) relate the findings to James (1890) paradox where experienced time seems to pass by quickly in passing, but stretches in retrospect (cf., James' views on the plasticity of subjective time; see Subsection: The Plasticity of Subjective Time).

Indeed, the study conducted by Martínez (1994) sheds light on how duration judgments when a delay interjects between the experience of an event to be temporally estimated and the actual duration judgment given. The last hypothesis of interest is as follows: Reproduced duration judgments made immediately after termination of the target interval will result in shorter reproductions than when reproduced duration judgments are made after the recognition task is presented. To elaborate, the secondary task was an object recognition task, by which a number of words are presented that either refer to the objects in the stimulus events subjects were exposed to earlier, or are filler words that do not correspond to the objects viewed earlier.

The nature of the secondary task requires subjects to not only recall the objects visually, but to translate the object in the stimulus events into lexical items (i.e., conventional verbal labels). If performance on the object recognition task is poor, then it would indicate that they allocated more attention to time, and as a result, would be more accurate in their duration reproduction judgments. On the other hand, if they perform well on the object recognition task, then it would indicate that they have paid the secondary task sufficient attention, and a result, their reproduced duration judgments should be shorter. This effect however has an alternative explanation: if subjects perform well on the object recognition task, it would indicate that they have verbally consolidated the objects seen, thereafter during the duration reproduction, they would more easily be able to inferentially reconstruct what they saw from long-term memory, and hence give relatively accurate duration reproductions (via a different route of decision making). This also shows how the current manipulation differs from Martínez's (1994) study: first, she used auditory events as the target interval to be reproduced, while the focus here was on visual events. Second, her recognition task was always given at the end of each trial, with only the preparatory task in between in some of the trials - while this in fact does test effects of memory load, it does not require a translation process from visual to verbal objects. Moreover, in the current study, subjects are required to maintain the visual objects (or their verbal counterparts) during the target interval itself, and not afterwards.

A valid question to ask concerning the relationship between the secondary task and subsequent duration reproductions is what the time course of consolidation of immediate perceptual inputs (cf., immediate memory) into a durable working memory representation is? Vogel, Woodman, and Luck (2006) found that, contrary to findings of past studies positing around 500 ms per item (Ward, Duncan, & Shapiro, 1996), consolidation is as fast as 50 ms per item. This, along with item limitations in visual working memory, have important bearings on the present study in the following ways: first, each stimulus event in this experiment has a duration of either 3000 ms (few stimuli condition) or 2000 ms (many stimuli condition), whereby the (fixed) physical duration of all the stimulus events per trial amounts to 12000 ms. Given that consolidation to visual working memory takes around 50 ms, this provides sufficient time for storing the item as well as verbal consolidation under bith prospective and retrospective conditions. Second, in the many stimuli trial, a total of six different stimuli are presented which subjects have to store - this clearly exceeds the visual working memory limitations.

Two non-mutually exclusive ideas can follow from this: Given the sufficient amount of time per stimuli in either of the stimuli quantity conditions (3000 ms or 2000 ms), subjects might be able to store the verbal labels upon viewing the visual stimuli, thereby later retrieving the verbal labels rehearsed earlier, and not the visual objects. Alternatively, the sufficient time for consolidation to working memory could perhaps be also sufficient for consolidation to long-term memory; this means that when subjects are performing the recognition task, they are relying on long-term memories and would as a result also draw from long-term memory resources to reconstruct the duration of the preceding visual stimulus events. If this is so, then it would indicate that reproducing the duration of the target interval (stimulus event ensembles) prior to the object recognition task relies primarily on working memory resources (despite that this is questionable given what is known about longer event durations greater than 2-3 s; see Ulbrich et al., 2006)), while providing reproduced duration judgments after the object recognition task relies primarily on long-term memory resources. Given that subjects draw from long-term memory (or even working memory) resources, it is unclear what the rate of decay per item is, and how that can vary from one individual to another. Despite this possibility, this is of relevance only if subjects perform poorly on the object recognition task, which is unlikely since the secondary task only tests object recognition, and not constructive recall, which eases demands on memory search (Fortin, Champagne, & Poirier, 2007).

To recapitulate some of the ideas mentioned about why the object recognition task was included, the following reasons are offered: to ensure that participants attend to the stimuli being presented, to test higher-order cognitive interference (via the mental translation of images into lexical items), to provide the opportunity of including filler trials to (partially) eliminate learning effects, and finally, to cloud the aims of the experiment under the retrospective paradigm. The latter of these points permitted the provision of a plausible (yet false) aim of the experiment; subjects were told that they will be performing a task that tests their recognition speed from memory [see Subsection: Design].

With respect to the choice of the fixed duration interval (12000 ms), some researchers (Ulbrich et al., 2006) have noted that reproduced short intervals of about 2-3 s tap into different mechanisms than intervals longer than 2-3s[24]. The major finding was that intervals longer than 2-3 s are usually reproduced underestimates of the target interval, unless the subject tested has a high working memory span. Given that the physical duration in he present study is 12000 ms, it brings to question what kind of cognitive processes are at play during duration reproductions, regardless of whether the paradigm is prospective or retrospective. As a result, the hypothesis regarding reproductions will be that not only all duration reproductions are underestimates, but also the kinds of judgments made essentially rely on long-term memory resources, via a process of inferential reconstruction (cf., Guyau's view on memory as organizing our temporal experience; see Subsection: Four Guyauian Pillar of Time Psychology - The Role of Dynamic Memory).

Finally, the methodological enterprise governing psychological time warrants some motivation for decisions made in the current study. As noted earlier, the method of reproduction has been seen as more accurate and reliable than other methods of duration estimation (Eisler, 1996; Zakay, 1990), and was therefore the method of choice. Both Eisler (1996) and Zakay (1990) also discussed the role that the inter-stimulus interval plays and how it might bias findings - in the present investigation, the insertion of the delayed duration judgment condition was deliberate, to further tease out effects of cognitive interference. Time researchers also (Roeckelein, 2000; Eisler, 1996; Zakay, 1990) caution about the time-order error, which states that identical stimuli presented in succession are not necessarily experienced as equal. This is often directed at research that aims to make comparisons between retrospective and prospective paradigms within the same experiment, where retrospective estimates are generally longer (Zakay, 1990). The time-order error does not apply to the present investigation, as each trial necessarily differs from the preceding trials with respect to the experimental manipulations, as well as different (non-repititive) stimuli across each trial. Lastly, plotting a psychophysical function (cf., scalar timing models) was not an option, as only a single duration (of stimulus events) was to be reproduced; furthermore, testing for such a function was beyond the scope of this study.

[24]This insight is derived from Karl von Vierordt's (1868) law, who stated that reproductions of short durations are generally longer than the standard, and reproductions of long intervals are shorter than the standard (Eisler, 1996).

5 Methods

5.1 Design

The design of this experiment had a 2 (stimulus complexity: simple or complex) x 2 (stimulus quantity: few or many) x 2 (duration judgment task delay: immediate or delayed), yielding a total of 8 different conditions. There were three dependent variables in the experiment: reproduced duration estimates for the duration judgment task,and reaction times and accuracy for the object recognition task.

All subjects participated in all conditions, which spanned 16 trials in total. Eight of these trials were fillers, consisting of only the object recognition task - the other eight included both the object recognition task as well as the duration judgment task. The fillers were included for two reasons: to mask the real aims of the experiment and to ensure the object recognition task was well practiced prior to making any duration judgments. The latter was controlled for to ensure that the first two trials of the experiment were fillers. Moreover, placing two filler trials at the start of the experiment adequately deals with the tricky nature of the retrospective paradigm - by providing fillers at the beginning of the experiment, any possible clues about the aim of the experiment are eliminated, paving the way for participants to retrospectively reproduce the target duration with little suspicion, if any.

In order to test reproduced duration estimates under the retrospective paradigm, 32 subjects were recruited for participation under the balanced design: four subjects per condition. Since only the first *real* trial (i.e., the third trial) can reveal any insights about retrospective duration judgments, a preset function was implemented that controls for the condition set during the first real trial (e.g., one condition set has complex stimuli, few stimuli, immediate duration judgment); the remainder of trials where counterbalanced across all conditions. To briefly recap, this means that four subjects will be exposed to each condition set. Despite that the remainder of trials are counterbalanced, the position of the trial type (filler or real) was fixed, to ensure that a participant is not exposed to two real trials in succession, hence potentially avoiding (duration) learning effects from trial to trial.

The object recognition task is a forced-choice task, whereby subjects have to indicate (as quickly as possible) whether or not they recognize the *object* (in the picture stimuli) the word presented *refers* to. Moreover, the words presented are split between words that *do* refer to a visual object presented earlier, and filler words that *do not* correspond to an object presented earlier. If the subject was on a few-stimuli trial (4 pictures), where each picture was presented for 3000 ms, then each word presented on the object recognition task for that trial also lasted 3000 ms. If the subject was on a many-stimuli trial (6 pictures), where each picture was shown for 2000 ms, then each of the words presented on the object recognition task for that trial was also displayed for 2000 ms. Given that there is an equal number of filler and real words, this means that in the few-stimuli condition, 8 words were presented (4 filler; 4 real), and for the many-stimuli condition, 12 words were presented (6 filler; 6 real).

As previously mentioned, the method of duration estimation in this experiment is reproduction [see Section: Present Study]. This was designed in the following way: the onset of the duration judgment task always begun with instructions explaining the subsequent duration judgment task to be performed, followed by an action preparation countdown timer (3...2...1), where each countdown number was displayed on screen separately. Once the countdown timer elapsed, a high-velocity spinning clock was displayed, thereafter subjects had to (by means of a button press) indicate when they believed the duration of the picture slideshow had elapsed - in other words, to reproduce the duration of the target interval. The possibility of stopping the clock timer (responding) had a lower limit of 4000 ms and an upper limit of 20000 - whereby responding prior to 4000 ms has no effect on the timer, and traversing the upper limit results in a miss. Two reasons are provided for the choice of a high-velocity spinning clock: first, with respect to displaying a spinning clock, it ensures that subjects are not simply reproducing an interval devoid of any content and second, with respect to its velocity, it eliminates any possibility of being used as an index for counting[25].

The dependent variables (reproduced duration estimates, object recognition accuracy, and object recognition reaction times) were entered into a repeated measures ANOVA with three levels (stimulus complexity, stimulus quantity, duration judgment delay) as within-subject factors. In examining possible covariates for the reproduced duration estimates, a three-level (stimulus complexity, stimulus quantity, duration judgment delay) repeated measures ANCOVA was carried out, to ensure that the object recognition task results were not a confounding factor for subjects' reproduced duration estimates on the duration judgment task. For all analyses, the acceptable level for inferring statistical significance was set at $p < 0.05$, whereas the acceptable level for inferring marginal statistical significance was set to $0.05 \leqslant p < 0.85$.

5.2 Participants

Subjects employed for the present study consisted of 32 young adults (aged 18-31 , M = 23, SD = 3.6; 14 males and 18 females). The subjects were primarily first-year psychology undergraduate students at the Universiteit van Amsterdam, recruited via subscription lists placed in the laboratory area at the Psychology department. Subjects were given 1 participation point in exchange for participating in this experiment. Each subject was required to sign an 'informed consent' form prior to experimentation. All subjects had normal or corrected-to-normal vision.

5.3 Apparatus & Stimuli

The task was presented on either one of two 17" TFT LCD monitors, each hooked to a Pentium 4 (1.5Ghz) Intel processor with 1Gb RAM. In order to avoid any potential button-press biases on the keyboard, a button pad (2 buttons) was hooked to each computer system, providing a convenient means for responding. Each system had Presentation © (v. 12.2), a critical timing software that can be used for psychophysical experiments. Testing was carried out in a brightly-lit room, to maintain subjects' alertness level. Participants were

[25]As will be shown later, this might have implications on subjects' arousal level, thereby increasing the rate of pulses emitted by the internal pacemaker (cf., attentional-gate model Block & Zakay, 2006).

seated approximately 60 cm away from the monitor. All stimuli were presented in the middle of the screen.

A total of 96 picture stimuli were obtained from Google Images ™. Given the variation in resolution and size, a Mac OS X software "Auto Resizer ©" was used for controlling image resolution and size (via batch processing). The stimuli used were static images of commonsense, everyday inanimate objects controlled for semantic effects (e.g., implied actions). The images used were either simple (46 stimuli) or complex (46 stimuli). In this study, complexity was narrowly defined as multi-dimensional variation in stimulus size, position, color, and background pattern (see Fetterman, 1996 for a Gibsonian approach to ecologically-valid stimuli). Each stimulus event denotes a single object (such as a chair, hammer, or light bulb). The complex pictures (see Figure 2, Appendix C) depict objects as seen in the world around us (perceptually rich), while simple pictures (see Figure 1, Appendix C) depict a single (perceptually-dull) object, placed on a white background. An animated duration cursor resembling a colorful clock (see Figure 3, Appendix C) was used for participants to mark the onset and offset of the reproduction of the target interval. The cursor spun at a high velocity in order to avoid being used as an index for counting. The remainder of stimuli consisted of fixation points, countdown preparation, and instruction pages, all of which where written directly into the Presentation © code.

5.4 Procedure

The experiment involved a single session comprising 16 trials (8 real; 8 filler) that lasted approximately 25 minutes. Each subject had to complete all 16 trials; this meant that each subject was exposed to all conditions. Subjects were asked to remove their watches and cell phones, and other electronic accessories - this was done to ensure that they do not use any aids during the duration judgment task. Subjects were initially not given a reason for removal of their accessories, but when asked, they were told that it might interfere with some of the equipment in the Audio-Visual room, where the testing took place. Zakay (1990) warned about such instructions, suggesting it could perhaps orient subjects to suspect what the aim of the experiment is about. For the present experiment, it is highly questionable whether subjects had any notion about the aims of the experiment, especially since the first two trials were fillers - a point at which subjects are relatively engaged in the experiment, hence preventing conscious reflection on the real aim of the experiment.

Prior to testing, each subject was required to fill in a personal information form, and an informed consent form. After, they were provided with the task instructions on paper (hardcopy), and were asked to reread the instructions again on the monitor, in addition to a brief oral explanation provided by the experimenter - these cautionary measures were taken to eliminate any confusion the subject might have about the task requirements. Moreover, there were two versions of the experiment: an English version and a Dutch version. The appropriate version of the experiment was assigned based on the subjects native language[26].

[26]Actually, while we asked for the subjects native language, we ensured that the subjects native language is also the language she/he is most fluent in.

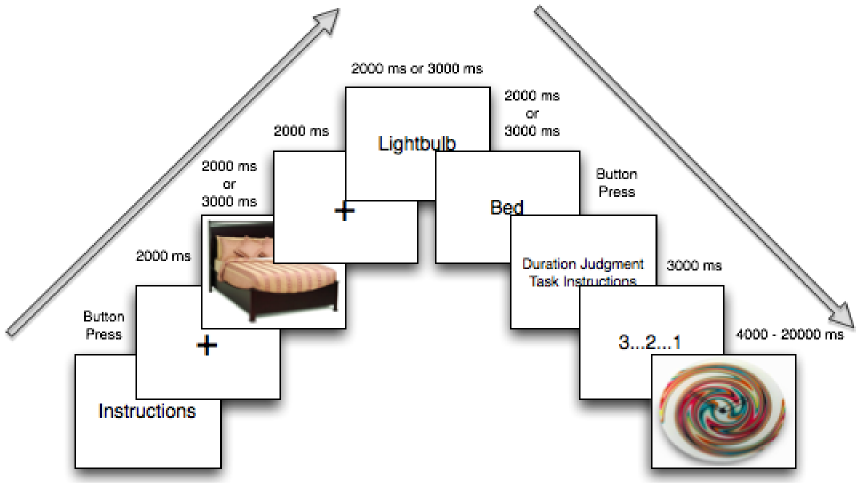

Figure 3: Schematic representation of the event-sequences for a single *real* trial exemplifying the simple stimuli condition and the delayed duration judgment condition.

Subjects were seated approximately 60 cm away from the computer monitor. Once they had fully understood the task requirements, they began the experiment. A schematic representation of the sequence of events for a single *real* trial comprising the simple stimuli condition and the delayed duration judgment condition can be seen in Figure 3, and a schematic representation of a single trial comprising the complex stimuli condition and immediate duration judgment condition is presented in Figure 4. As shown, upon starting the experiment, a fixation point was displayed for 2000 ms. After, the picture slideshow (representing the target interval) was given. Each picture slide lasted for 3000 ms in the few stimuli condition (4 pictures), and 2000 ms for the many stimuli condition (6 pictures), with both having a total physical duration of 12000 ms across every trial. After the termination of the picture slideshow, subjects had to complete either the object recognition task prior to the duration judgment task indicating they were in a delayed duration judgment trial (see Figure 3), or complete the duration judgment task prior to the object recognition task, indicating they were in an immediate duration judgment trial (see Figure 4).

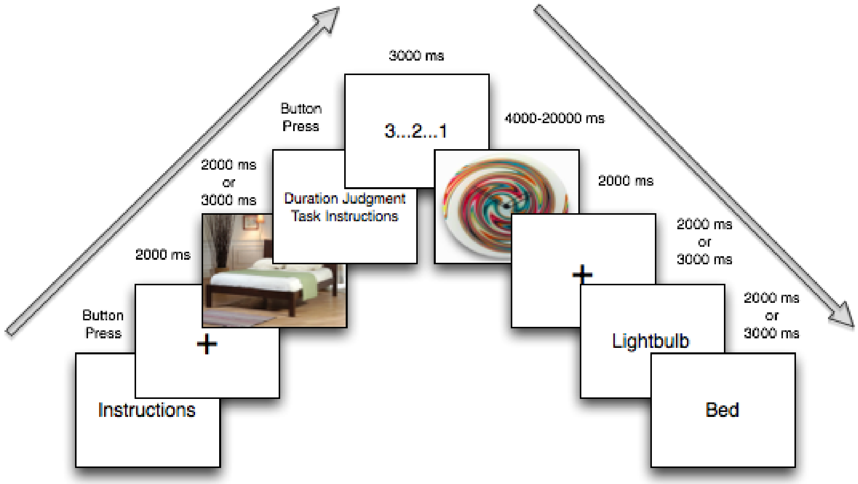

Figure 4: Schematic representation of the event-sequences for a single *real* trial exemplifying the complex stimuli condition and the immediate duration judgment condition.

For the duration judgment task, subjects were given another instruction page that was to be terminated by a button press. After pressing a button to continue, a countdown timer was given. Each number (3...2...1) was displayed on a single page[27] lasting for 1000 ms. After the countdown, a clock began spinning (at a high velocity), whereby subjects had to reproduce the target duration (duration of the previously shown picture events). The clock to be stopped (akin to a kitchen timer) had a lower limit by which it can be terminated of 4000 ms, and an upper limit of 20000 ms, in which 12000 ms marked the duration of the target interval.

For the object recognition task, subjects were first exposed to a fixation point lasting 2000 ms. Upon termination of the fixation point, a series of words were presented, some of which correspond to objects in the previously shown picture slideshow, and some of which do not (fillers). A single word was presented on a page, that lasted for either 3000 ms (few stimuli condition) or 2000 ms (many stimuli condition). If the subject was in a few stimuli trial, a total of 8 words were presented (4 corresponding to seen objects; 4 fillers), and a total of 12 words were presented (6 corresponding to seen objects; 6 fillers) if the subject was in a many stimuli trial.

After completion of the object recognition task or the duration judgment task (depending on the conditions in the trial), a fixation point was presented (2000 ms) that indicated the start of the next trial. After the last trial was completed, a screen thanking the subjects for participation was displayed. At the end of the experimental session, an exit-interview was given to each subject[28], assessing general questions about them and the task they completed, on a 5-point scale [See Subsection: Exit Interview Correlations: Object Recognition RTs and Reproduced Duration Estimation RTs].

[27]In the schematic representations, the countdown timer is displayed as if all the numbers were shown on a single page - this was done for illustrative purposes only.

[28]Subjects were also given some candy for their participation.

6 Results

6.1 Duration Judgment Task

Within the duration judgment task, two different assessments were made: Reaction times, which indicate how short or long participants estimated the target interval to be, and accuracy which determines how close participants were to the correct response (12,000 ms). In addition, two types of trials were of interest: the first trial containing the duration judgment task (indicative of the retrospective paradigm) and all other trials that contain the duration judgment task (indicative of the prospective paradigm).

Non-normally Distributed Reproduced Duration Estimation RTs

Duration reproductions for the duration judgment task [M = 8148 ms, SE = 192.43] did not exhibit a normal distribution [*Median* = 7614, *Range* = 15219] due to positive skewness [*Skewness* = 1.02, *Skewness SE* = .15] and positive kurtosis [*Kurtosis* = 1.072, *Kurtosis SE* = .30]. The Shapiro-Wilk test of normality [*Statistic* = .928, p = .000] was significant, indicating that the present data is not normally distributed. The shape of the distribution for duration estimates is presented in Appendix A.

In order to normalize the results obtained, a logarithmic (log10) transformation was applied to the duration reproductions. The results after the logarithmic transformation [M = 3.88 ms, SE = .01, *Median* = 3.88, *Range* = .68] had greatly reduced the positive skewness [*Skewness* = .18, *Skewness SE* = .15], while over-reducing kurtosis to a negative value [*Kurtosis* = -.60, *Kurtosis SE* = .30]. Despite the logarithmic transformation, the data was still not normally distributed [*Shapiro-Wilk Statistic* = .98, p = .002]. The shape of the distribution after the logarithmic transformation can be seen in Appendix A.

Despite that the data was not normally distributed for the duration reproductions (even after logarthmic transformations), parametric tests were nevertheless conducted. The use of parametric tests are justified due to the following: first, it is not surprising that there were many outliers, as the duration judgment task was difficult, and as a result participants' scores were not expected to center around an average. Second, as mentioned previously, parametric tests are quite powerful, and despite that the gathered data are not normally distributed according to Shapiro-Wilk's test, both skewedness and kurtosis do not exceed the 2-point range (-2 or 2), which makes the data usable. The logarithmically transformed duration reproductions for the retrospective and prospective paradigms considered together are presented in Appendix A.

Reproduced Duration Estimation Reaction Times

Retrospective paradigm by Preset. A between-subjects ANOVA was conducted to reveal whether the preset for the first trial only had an effect on participants' duration reproductions. The effect of preset on duration reproductions for the retrospective paradigm trials did not reach statistical significance, such that duration reproductions did not significantly differ across the different presets [$F(7, 31) = .72$, $MSE = 1.22$, $p = .654$]. The mean duration reproductions for each preset are presented in Table 1.

Effect of Preset on Duration Estimates (RT)			
Preset	**Mean**	**Std. Deviation**	**N**
Preset 1	9612.45	2813.7473	4
Preset 2	8086.0679	1534.27203	4
Preset 3	10901.8	5950.74498	4
Preset 4	10723.875	4763.79021	4
Preset 5	11036.7	5659.89749	4
Preset 6	6431.4357	2105.06127	4
Preset 7	7318.375	4432.13224	4
Preset 8	9518.475	3218.12901	4

Table 1: Mean reproduced duration estimates by preset for the retrospecive paradigm.

Retrospective paradigm by Factor. A between-subjects ANOVA was conducted in order to assess whether each factor (complexity, quantity, delay) and their interaction had an effect on duration reproductions for the first trial. The complexity of stimuli had no significant effect on participants' duration reproductions [$F(1,\ 31) = .75$, $MSE = 1.26$, $p = .396$], such that participants did not significantly differ in their mean duration reproductions in the simple stimuli trials [$M = 9831$ ms, $SD = 3875$] than in the complex stimuli trials [$M = 8576$ ms, $SD = 4098$]. The number of stimuli presented did not have a significant effect on duration reproductions [$F(1,\ 31) = .58$, $MSE = 5.43$, $p = .576$], indicating that presenting a few number of stimuli did not significantly affect participants' mean duration reproductions [$M = 9616$ ms, $SD = 4450$] than when many stimuli were presented [$M = 8792$ ms, $SD = 3534$]. Manipulating the order of presentation of the duration judgment task did not have a significant effect [$F(1,\ 31) = .50$, $MSE = 8.44$, $p = .486$], such that participants' mean duration reproductions did not differ significantly when the duration task was presented immediately after the picture slideshow [$M = 9717$ ms, $SD = 4624$], than when it was presented after the object recognition task [$M = 8690$ ms, $SD = 3273$].

Interaction effects between stimulus complexity and stimulus quantity did not show a significant effect on participants' duration reproductions [$F(1,\ 31) = .62$, $MSE = 1.04$, $p = .44$]. An interaction between stimulus complexity and presentation order of the duration judgment task also did not exhibit a significant effect on duration reproductions [$F(1,\ 31) = .02$, $MSE = 245600$, $p = .905$]. Interaction between the quantity of stimuli presented and the order of presentation of the duration judgment task also did not reach statistical significance [$F(1,\ 31) = 1.97$, $MSE = 3.32$, $p = .17$]. Finally, an interaction between all three factors failed to exhibit a significant effect on participants' duration reproductions [$F(1,\ 31) = .88$, $MSE = 1.49$, $p = .357$].

Collapsing the Retrospective and Prospective paradigms. Since neither the preset nor the factors and their interactions in the first trial (retrospective paradigm) had a significant effect on duration reproductions, both the retrospective and prospective paradigms will subsequently be considered together.

A within-subjects MANOVA with complexity (2 levels: simple and complex), quantity (2 levels: few and many) and delay (2 levels: immediate and delayed) revealed that complexity had no significant effect on reproduced duration estimates [$F(1,\ 31) = .11$, $MSE = 239164.66$, $p = .743$], such that participants did not significantly differ in their reproduced duration estimates when the complexity of the stimuli presented was simple [$M = 8117$ ms, $SE = 405.66$], rather than complex [M = 8178 ms, SE = 408.84]. Varying the quantity of the stimuli presented revealed a significant effect on participants' reproduced duration estimates [$F(1, 31) = 14.58$, $MSE = 7.68$, $p = .001$], such that participants in the few stimuli trials perceived the target interval as shorter [M = 7600 ms, SE = 390.04] than in the many stimuli trials [M = 8695.15 ms, SE = 451.21]. Manipulating the order by which the duration judgment task is presented had a marginally significant effect on participants' duration reproductions [$F(1, 31) = 3.18$, $MSE = 1.74$, $p = .084$], suggesting that participants tended to give shorter duration reproductions when the duration judgment task was presented immediately after the picture slideshow [M = 7887 ms, SE = 440.94], than when the duration judgment task was presented after [M = 8409 ms, SE = 403.80]. The mean duration reproductions for each factor are presented in Figure 3.

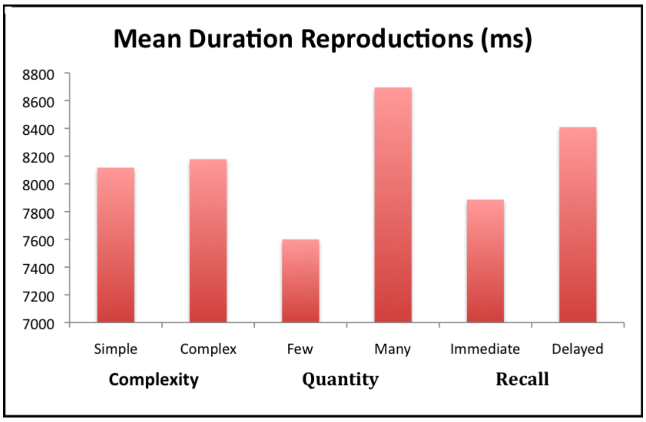

Figure 5: Mean reproduced duration estimates on the duration judgment task.

An interaction between stimulus complexity and stimulus quantity had no significant effect on participants' duration reproductions [$F(1, 31) = .06$, $MSE = 385891.66$, $p = .812$]. An interaction between stimulus complexity and order of presentation of the duration judgment task also had no significant effect on duration reproductions of the target interval [$F(1, 31) = .14$, $MSE = 552919.71$, $p = .711$]. The interaction between stimulus quantity and the order of presentation of the duration judgment task likewise did not exhibit a significant effect on participants' duration reproductions [$F(1, 31) = .00$, $MSE = 1456.65$, $p = .986$]. Finally, an interaction between all three factors (complexity, quantity, delay) had no significant effect on duration reproductions of the target interval [$F(1, 31) = .36$, $MSE = 2.26$, $p = .553$].

Duration Estimation: Underestimating or Overestimating the Reproduction of the Target Interval?

Insight into whether participants underestimated the target interval or overestimated was obtained by subtracting the physical duration from participants' duration reproductions. Listed below are the effects of each factor on participants' duration reproduction accuracy relative to the physical duration of the target interval (12,000 ms).

A within-subjects MANOVA with complexity (2 levels: simple and complex), quantity (2 levels: few and many) and delay (2 levels: immediate and delayed) showed that complexity had no significant effect on duration reproductions [$F(1, 31) = .11$, $MSE = 239164.66$, $p = .743$], indicating that participants did not significantly differ in how much they underestimated the target interval in the simple stimuli trials [M = -3883 ms, $SE = 405.66$], than in the complex stimuli trials [M = -3822 ms, $SE = 408.84$]. Varying the quantity of the stimuli presented revealed a significant effect on participants' duration reproductions [$F(1, 31) = 14.58$, $MSE = 7.68$, $p = .001$], such that participants in the few stimuli trials significantly underestimated the reproduced target interval [M = -4400.04 ms, $SE = 390.04$] than in the many stimuli trials [M = -3305 ms, $SE = 451.21$]. Manipulating the order by which the duration judgment task is presented had a marginally significant effect on participants' duration reproductions [$F(1, 31) = 3.18$, $MSE = 1.74$, $p = .084$], such that participants tended to give shorter reproductions when the duration judgment task was presented immediately after the picture slideshow [M = -4113 ms, $SE = 440.94$], than when the duration judgment task was presented after [M = -3591 ms, $SE = 403.80$]. These results clearly indicate that participants on average underestimated the target interval. The mean duration reproductions relative to the target interval duration for each factor are presented in Figure 4.

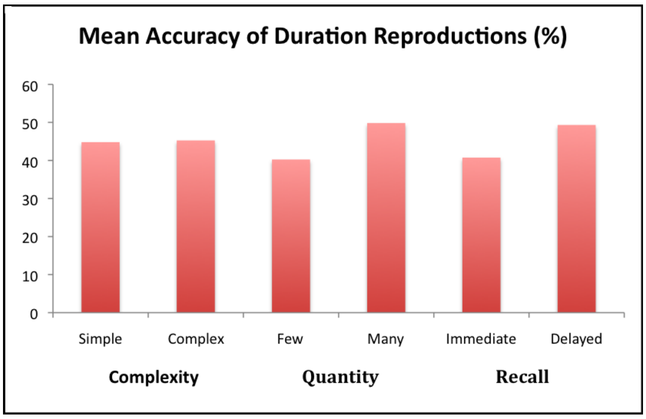

Figure 6: Mean reproduced duration estimates by factor relative to the physical duration (where 12,000 ms = 0 ms) in the duration judgment task.

6.2 Object Recognition Task

Non-normally Distributed Object Recognition RTs

The reaction times for the object recognition task (correct responses) [M = 803 ms, $SE = 13.16$] did not exhibit a normal distribution [$Median = 764$, $Range = 1763$] due to positive skewness [$Skewness = .59$, $Skewness\ SE = .15$] and positive kurtosis [$Kurtosis = 2.77$, $Kurtosis\ SE = .30$]. This was verified by checking the Shapiro-Wilk test of normality [$Statistic = .94$, $p = .000$], indicating that the null hypothesis of normality must be rejected. The shape of the distribution for object recognition reaction times can be seen in Appendix B.

As was done for the duration judgment task, a logarithmic (log10) transformation was applied to the results. The results after the logarithmic transformation [M = 2.90 ms, SE = .01, $Median$ = 2.89, $Range$ = .66] had only slightly reduced the positive skewness [$Skewness$ = .38, $Skewness$ SE = .15], while drastically reducing positive kurtosis [$Kurtosis$ = .20, $Kurtosis$ SE = .30]; however, such a transformation was not sufficient to make the data normally distributed [*Shapiro-Wilk Statistic* = .99, p = .023]. The shape of the distribution for object recognition reaction times after the logarithmic transformation is presented in Appendix B.

While it is evident from the above that the reaction times for the object recognition task are not normally distributed, parametric tests were nevertheless applied, and this was for two reasons: First, reaction time data are often positively skewed, and with respect to the current data, it is likely that there were too many outliers. Finally, parametric tests are more powerful than applying non-parametric tests, and while the data might not be normally distributed according to Shapiro-Wilk's test, both skewness and kurtosis do not exceed the 2-point range, which makes the data overall acceptable. As was done for the duration judgment task, the reaction times after the logarithimic transformation are presented in Appendix B.

Reaction Times

A within-subjects MANOVA with complexity (2 levels: simple and complex), quantity (2 levels: few and many) and delay (2 levels: immediate and delayed) revealed that complexity had a marginally significant effect on correct responses [$F(1, 31) = .08$, MSE = 59648.93, p = .077], such that participants tended to respond slower in the simple stimuli trials [M = 818 ms, SE = 32.34] than in the complex stimuli trials [M = 787 ms, SE = 26.02]. The quantity of stimuli also had a marginally significant effect on correct responses [$F(1, 31) = 4.02$, MSE = 111413.66, p = .054], indicating that subjects tended to respond slower when few stimuli were presented [M = 824 ms, SE = 29.78], than when many stimuli were presented [M = 782 ms, SE = 30.23]. Presenting the duration estimation task immediately or after the object recognition task had no significant effect on reaction time speed for correct responses [$F(1, 31) = 2.44$, MSE = 72722.06, p = .128], such that participants did not respond significantly faster when the duration judgment task was delayed [M = 786 ms, SE = 29.61], than when it was presented immediately after the picture slideshow [M = 820 ms, SE = 30.65]. The mean reaction times for each of the aformentioned conditions is presented in Figure 1.

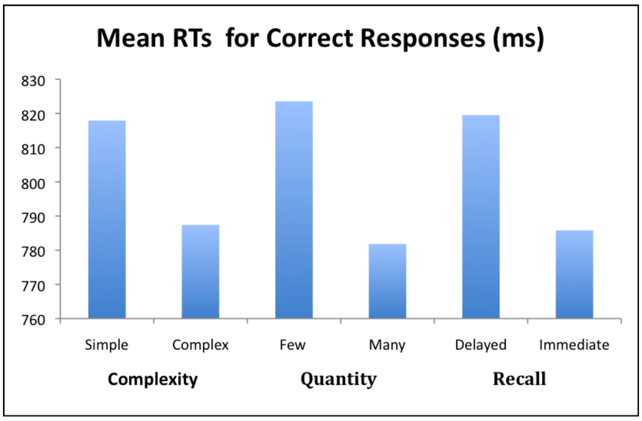

Figure 7: Mean reaction times for correct responses on the object recognition task.

An interaction between stimulus complexity and stimulus quantity revealed no significant effect on reaction times for correct responses [$F(1, 31) = .04$, $MSE = 817.81$, $p = .851$]. An interaction between stimulus complexity and order of presentation of the duration judgment task also had no significant effect on speed of responding correctly [$F(1, 31) = .93$, $MSE = 10616.24$, $p = .342$]. The interaction between stimulus quantity and order of presentation of the duration judgment task however did have a significant effect on how fast participants responded [$F(1, 31) = 5.75$, $MSE = 163268.50$, $p = .023$]. Finally, an interaction between all three factors (complexity, quantity, delay) had no significant effect on how fast participants responded [$F(1, 31) = 1.25$, $MSE = 12546.57$, $p = .273$].

Correct Responses

With respect to how well participants performed on the object recognition task (correct responses), varying the complexity of the stimuli revealed no significant effect [$F(1, 31) = 1.19$, $MSE = 125.39$, $p = .284$], such that participants did not perform significantly better in the complex stimuli trials [$M = 90.82$ %, $SE = 1.52$] than in the simple stimuli trials [$M = 89.42$ %, $SE = 1.56$]. Varying the quantity of stimuli presented had a marginally significant effect on the number of correct responses made [$F(1, 31) = 3.91$, $MSE = 805.73$, $p = .057$], where participants tended to perform better when fewer stimuli were presented [$M = 91.90$ %, $SE = 1.10$], than when many stimuli were presented [$M = 88.35$ %, $SE = 2.08$]. Presenting the duration judgment task immediately or after the object recognition task had a significant effect on the performance of participants on the object recognition task [$F(1, 31) = 4.96$, $MSE = 1348.27$, $p = .033$], such that participants performed better when the object recognition task immediately followed the picture slideshow [$M = 92.42$ %, $SE = .95$], than when the object recognition task was presented after the duration judgment task [$M = 87.83$ %, $SE = 2.27$]. The mean reaction times for each of the factors is presented in Figure 2.

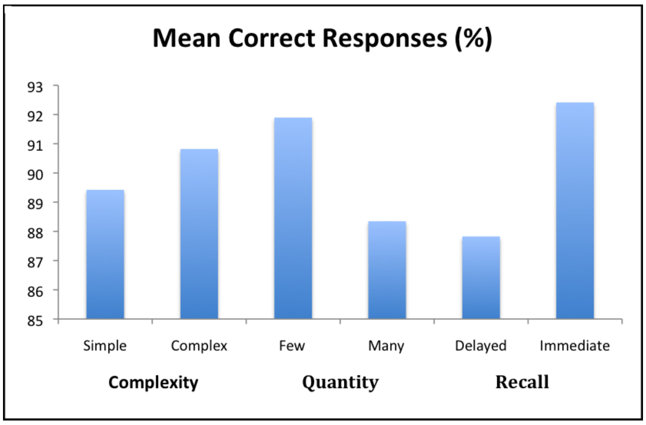

Figure 8: Mean correct responses on the object recognition task.

Interaction effects between stimulus complexity and stimulus quantity failed to show a significant effect on the number of correct responses participants made on the object recognition task [$F(1, 31) = 1.35$, $MSE = 149.81$, $p = .255$]. An interaction between stimulus complexity and presentation order of the object recognition task also did not exhibit a significant effect on correct responses [$F(1, 31) = .11$, $MSE = 19.60$, $p = .739$]. Interaction between the quantity of stimuli presented and the order of presentation of the object recognition also did not reach statistical significance [$F(1, 31) = .04$, $MSE = 5.49$, $p = .844$]. Finally, an interaction between all three factors did not have a significant effect on participants' correct responses [$F(1, 31) = .58$, $MSE = 83.08$, $p = .454$].

6.3 Global Object Recognition RTs as Covariates for Mean Reproduced Duration Estimation RTs

A three-factor (complexity, quantity, delay) within-subjects ANCOVA was conducted in order to ensure that the object recognition task results were not a confounding factor for participants' reproduced duration estimates on the duration judgment task.

Complexity with global object recognition reaction times as covariates had no significant effect on reproduced duration estimates [$F(1, 30) = .37$, $MSE = 874043.23$, $p = .549$], such that participants did not significantly differ in their duration reproductions when the complexity of the stimuli presented was simple [$M = 8015$ ms, $SE = 435.51$], rather than complex, with global object recognition reaction times given as covariates [$M = 8108$ ms, $SE = 427.68$]. Varying the quantity of the stimuli with global object recognition reaction times as covariates did not have a significant effect on participants' duration reproductions [$F(1, 30) = .38$, $MSE = 2.15$, $p = .543$], such that participants in the few stimuli trials did not significantly differ in their duration reproductions [$M = 7514$ ms, $SE = 412.41$] than in the many stimuli trials [$M = 8609$ ms, $SE = 477.87$]. Manipulating the order by which the duration judgment task is presented with global object recognition reaction times as covariates did not have a significant effect on participants' duration reproductions [$F(1, 30) = 1.36$, $MSE = 8.09$, $p = .252$], such that participants did not differ significantly in their duration reproductions when the duration judgment task was presented immediately after the picture slideshow [M = 7785 ms, SE = 469.63], than when the duration judgment task was presented after [M = 8338 ms, SE = 424.03]. Global object recognition reaction times as covariates did not have any significant effect on participants' duration reproductions for each respective condition, indicating that the participant response speed on the object recognition task did not influence their duration reproductions of the target interval. The means of the duration reproductions for each factor with the global object recognition reaction times as covariates are presented in Figure 5.

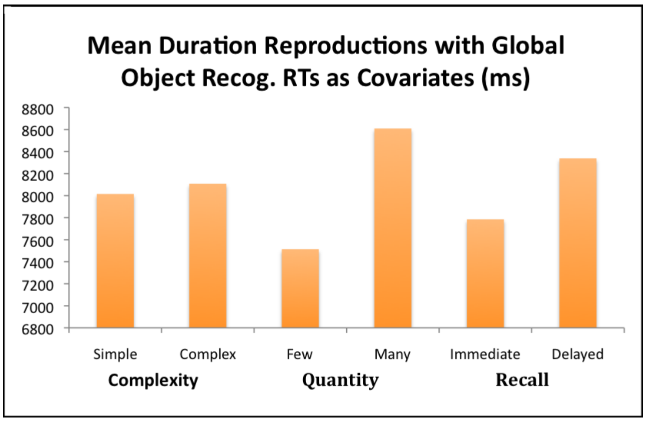

Figure 9: Mean reproduced duration estimates with global object recognition reaction times as covariates in the duration judgment task.

6.4 Trial-by-trial evolution of performance on the Duration Judgment Task

In order to assess whether or not participants had implicitly learned the duration of the target interval towards the end of the experiment, a one-factor (trial position) MANOVA was conducted, with the aim of gaining insight into the evolution of participants' performance (by looking into participants' duration reproductions as well as their reproduction accuracy relative to the target interval) throughout the experiment.

Participants' duration reproductions with respect to trial position had a marginally significant effect [$F(7, 217) = 2.01$, $MSE = 1.02$, $p = .055$], indicating that on average participants had a tendency to give different duration reproductions as they progressed from trial to trial. As participants progressed throughout the experiment, they had a general tendency to underestimate the duration of the target interval. On the first trial[29], participants had a mean duration estimate of 9204 ms [SD = 3.98]. After the first trial, there was a decrease in mean duration reproductions [M = 8191 ms, SD = 3.58], followed by a slight increase on the third trial [M = 8701 ms, SD = 3.17]. For the fourth [M = 7731.968 ms, SD = 2.281] and fifth trial [M = 7555.040 ms, SD = 2.608], there was a sharper decrease in duration reproductions, respectively. After the

[29]The position of the relevant trials in the experiment where participants are presented with the duration task are as follows: 3, 5, 7, 9, 11, 12, 14, 16. For simplicity, the 1-8 range will be used in reporting the results.

fifth trial, there was a gradual increase in duration reproductions from the sixth [M = 7666 ms, SD = 2.73] trial, to the seventh trial [M = 7948 ms, SD = 2.59], and finally to the eighth trial [M = 8184 ms, SD = 3.30]. Overall, the lowest reproduced duration estimates were on the fifth trial, with a gradual increase thereafter. However, the mean difference between performance on the duration judgment task on the first trial and the last trial was by no means significant [*Mean difference* = 1020 ms, SE = 585.06, p = 1.000]. The trial-by-trial mean duration reproductions are presented in Figure 6.

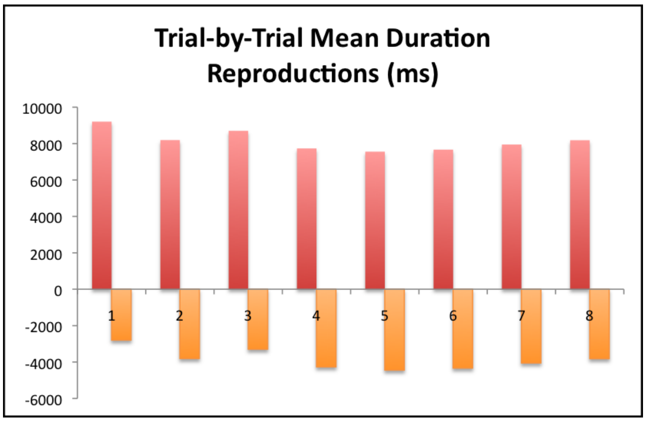

Figure 10: *Top:* Trial-by-trial mean reproduced duration estimates on the duration judgment task. *Bottom:* Trial-by-trial mean reproduced duration estimates relative to the target interval duration (0 ms).

6.5 Exit Interview Correlations: Object Recognition RTs and Reproduced Duration Estimation RTs

For both the object recognition task and the duration judgment task, a one-tailed[30] A Pearson-correlation analysis was conducted. This analysis aimed at identifying whether or not the mean exit interview scores for participants correlated with duration reproductions in the duration judgment task, and with response speed in the object recognition task. The results of the correlation analysis for both tasks are depicted below.

Reproduced Duration Estimation RTs: The perceived difficulty of the object recognition task [M = 2.3 , SD = .72] did not significantly correlate with participants' duration reproductions [r = .16, R^2 = .02, p = .198], such that participants' perceived difficulty of the object recognition task accounted for only 2.4% of the variability of their duration reproductions. The perceived difficulty of the duration judgment task [M = 3.38 , SD = .72] did not have a significant correlation with participants' duration reproductions [r = .09, R^2 = .01, p = .305], accounting for only 0.9% of the variance. The amount of effort deployed in doing the experiment [M = 3.8 , SD = .82] did not significantly correlate with participants' duration reproductions [r = .07, R^2 = .01, p = .356], accounting

[30]A one-tailed and not a two-tailed correlation analysis was carried out since we already had predictions about the relationships between the questions in the exit interview and participants' performance on both tasks.

for only 0.5% of the variance. Attentiveness and alertness of the participants [M = 4.03 , SD = .82] throughout the experiment did not significantly correlate with their duration reproductions [r = -.16, R^2 = .03, p = .188], accounting for only 2.6% of the variance. Rushing to finish the experiment [M = 1.97 , SD = .90] did not correlate with participants' duration reproductions on the duration judgment task [r = -.19, R^2 = .04, p = .152], explaining only 3.5% of the variance.

Participants' motivation throughout the experiment [M = 4.06 , SD = .62] did not significantly correlate with their duration reproductions [r = -.35, R^2 = .12, p = .02], accounting for only 0.1% of the variance. Participants' concentration throughout the experiment [M = 4.06 , SD = .88] did not correlate with their duration reproductions [r = -.35, R^2 = .12, p = .024], explaining only 1.6% of the variance. Participants' perceived calmness in general [M = 3.75 , SD = .984], marginally correlated with their duration reproductions [r = .30, R^2 = .09, p = .051], such that the calmer they are in general, the greater the tendency for higher duration reproductions; such a correlation however only accounts for 8.7% of the variance. Participants' proclaimed general level of anxiety [M = 2.16 , SD = 1.05] marginally correlated with their duration reproductions [r = -.28, R^2 = .08, p = .059], such that the more anxious they are in general, the greater the tendency for giving lower duration reproductions; such a correlation however only accounts for 8.0% of the variance. Finally, the perceived level of having to finish a task as quick as possible before being able to relax [M = 2.44 , SD = .91] did not significantly correlate with participants' duration reproductions [r = -.20, R^2 = .04, p = .14], whereby their perceived level of accomplishment in order to relax accounted for only 3.9% of the variance.

Object Recognition RTs: The perceived difficulty of the object recognition task [M = 2.25 , SD = .72] did not significantly correlate with response speed on the object recognition task [r = .21, R^2 = .04, p = .128], such that participants' perceived difficulty of the object recognition task accounted for only 4.3% of the variability of their response speed. The perceived difficulty of the duration judgment task [M = 3.38 , SD = .72] had a significant correlation with response speed on the object recognition task [r = .40, R^2 = .16, p = .011], whereby the more difficult participants perceived the duration judgment task, the longer they took to respond on the object recognition task; however, the perceived difficulty of the duration judgment task explained only 16.2% of the variance. The amount of effort deployed in doing the experiment [M = 3.8 , SD = .82] significantly correlated with response speed on the object recognition task [r = -.44, R^2 = .19, p = .006], such that the more effort participants put in, the faster their reaction times were on the object recognition task; however, the effort participants deployed explained only 18.9% of the variance. Attentiveness and alertness of the participants [M = 4.0 , SD = .82] throughout the experiment significantly correlated with response speed on the object recognition task [r = -.34, R^2 = .12, p = .029], such that the more attentive they were, the faster their reaction times; however, their attentiveness explained only 11.5% of the variance. Rushing to finish the experiment [M = 1.97 , SD = .90] had no correlation whatsoever on participants' response speed on the object recognition task [r = .00, R^2 = .00, p = .5].

Participants' motivation throughout the experiment [M = 4.1 , SD = .62] significantly correlated with their reaction times on the object recognition task [r = -.35, R^2 = .12, p = .024], such that the more motivated they were, the faster their reaction times were on the object recognition task; however, such a correlation explained only 12.3% of the variance. Participants' concentration throughout the experiment [M = 4.1 , SD = .88] was marginally correlated with their reaction times on the object recognition task [r = -.35, R^2 = .12, p = .024], such that the more concentrated they were, the greater the tendency to have faster reaction times on the object recognition task; however, this correlation explained only 7.7% of the variance. Participants' perceived calmness in general [M = 3.8 , SD = .98], did not correlate with their reaction time performance on the object recognition task [r = -.02, R^2 = .00, p = .45], whereby their perceived calmness accounted for only .04% of the variance. Participants' proclaimed general level of anxiety [M = 2.2 , SD = 1.05] marginally correlated with their reaction time performance on the object recognition task [r = .25, R^2 = .06, p = .082], such that the more anxious they are in general, the greater the tendency for slower reaction times on the object recognition task; such a correlation however only accounts for 6.4% of the variance. Finally, the perceived level of having to finish a task as quick as possible before being able to relax [M = 2.4 , SD = .91] did not significantly correlate with participants' reaction times on the object recognition task [r = .18, R^2 = .03, p = .160], whereby their perceived level of accomplishment in order to relax accounted for only 3.3% of the variance.

7 Discussion

Reproduced Duration Estimates The first thing to note is that stimulus complexity, quantity, and induction of cognitive interference did not have any effect on reproduced duration estimates under the retrospective paradigm. This result may in fact not be too surprising, as it appears that truly assessing retrospective reproduced duration estimates to some extent poses a catch-22. This is justified by the following reasoning steps: Under a retrospective paradigm, the subject is unaware that she/he will be asked to provide a duration judgment, and instead believes the study is testing something else (e.g., how fast can she/he recognize an object). This means that the duration judgment task has to happen after the start of the experiment, with the subject under the impression that the task involves, for example, (memory) recognition ability. However, if this is the case, then the subject might do one of two things: a) Not unlikely, the subject may not take the duration judgment task seriously, thinking that it is not a task the experimenter is primarily interested in; otherwise why would the experimenter not have given instructions about it? b) The subject may not fully understand what she/he has to do the first time the duration judgment task is given - this was evident by a number if subjects who were disqualified because they did not respond on the first duration judgment task given. Moreover, providing a practice trial for the duration judgment task quite obviously defeats the purpose of testing retrospective duration judgments.

Since reproduced duration estimates were not affected by the experimental manipulations under the retrospective paradigm, both prospective and retrospective paradigms were subsequently considered together[31]. Moreover, by

[31]We are almost certain that this is a highly contestable decision, given that the two

avoiding the comparison of the two paradigms, the possibility of a time-order error (Eisler, 1996; Zakay, 1990) is eliminated, despite that such an error would not have been strongly applicable for the present experiment. The results (for both paradigms) reveal that reproduced duration estimates are significantly affected by the quantity of stimuli presented, marginally affected by cognitive interference (delay), and completely unaffected by the complexity of the stimuli. It also appears that interactions between the factors did not affect reproduced duration estimates. Also, it is evident that all duration reproductions were underestimates, lending further support to the claims made by Ulbrich et al. (2006), as well as confirming Vierordt's law. Since there were no interaction factors, each factor will be considered separately below.

The results showing that the visual complexity of stimuli did not affect reproduced duration estimates runs contrary to the predictions made in the present work. This effect was exhibited for both retrospective and prospective paradigms. While stimulus complexity was found to affect duration estimates under the retrospective paradigm (Block & Zakay, 1997), the present finding lends further support that complexity does not affect prospective reproduced duration estimates, contrary to the findings of Macar (1996). The most parsimonious explanation for the lack of an effect is that there was not a sufficient difference between the complex and the simple stimuli. Moreover, given that the experiment stressed speed and accuracy on the object recognition task, it could be that subjects consolidated only the verbal label of the complex and simple objects, despite attending to the complex features when the complex stimuli were presented.

Varying the quantity of the stimuli presented while keeping the physical duration constant revealed a significant effect on reproduced duration estimates, such that fewer stimuli resulted in shorter duration reproductions than when many stimuli were presented. This finding is in direct conflict with the findings of Predebon (1996a, 1996b), who found that a greater number of stimuli resulted in shorter prospective duration reproductions. However, this finding is in line with the finding of Macar (1996). This result also falls within the predictions made in this experiment - presenting more stimuli should result in a greater number of events indexed in (long-term) memory, hence lengthening the reproduced duration. Arguably, such an explanation applies only to retrospective duration judgments, where attention to time is absent (Block & Zakay, 2006; Block, 2003; Block & Zakay, 1996). Nevertheless, it was argued earlier that due to the simplicity of the secondary task and the long target interval (12000 ms), it would appear that subjects are actively reconstructing what they saw earlier - in the case of presenting many stimuli, they have a greater number of events to retrieve, hence giving longer duration reproductions.

Introducing a secondary task between viewing the stimulus events and the subsequent duration judgment task had a marginally significant effect on reproduced duration estimates, such that presenting the duration judgment task immediately after the termination of the picture slideshow resulted in shorter duration reproductions than when it was presented after the object recognition task. This result lends further support to the findings of Martínez (1994), who also found prospective duration reproductions to be longer after a delay.

paradigms tap into different processes. However, if there were no effects from the manipulated variables, then considering both together should not provide any confounds.

However, in the present study, the delay consisted of a secondary task that was hypothesized to cause interference - the ensuing interpretation is that after performing the object recognition task, subjects had firmly consolidated the stimulus events into long-term memory, consequently retrieving the events by active reconstruction. This also further supports James' insights about the experience of time in passing and in retrospect,

Controlling for object recognition reaction times as covariates for the duration reproductions showed no effect on duration reproductions. As predicted, the object recognition task was relatively easy to complete, and hence did not influence duration reproductions. Concerning trial-to-trial evolution of subjects' duration reproductions, only a marginal effect was found, suggesting that subjects had a tendency to give different duration reproductions from trial to trial. This was marked by a slight shortening of duration reproductions after the first trial, and with a slight increase on the final trial. The purpose of such an analysis was to check whether any form of implicit learning took place across trials, independent of factor manipulations. Indeed, it seems that no such learning took place.

Object Recognition Performance The results show that object recognition reaction times for correct responses are marginally affected by the complexity of stimuli presented, marginally affected by varying the quantity of stimuli, and unaffected by introducing cognitive interference (delay). With respect to stimulus complexity, subjects tended to respond faster when the stimuli were complex than when the stimuli were simple. This suggests that complex stimuli are easier to consolidate, and as a result are more readily available for retrieval upon subsequent recognition probing. Varying the quantity of the stimuli showed that subjects tended to respond slower when few stimuli were displayed than when many stimuli were shown. This is an unexpected finding since subjects had fewer words to later recognize, as well as more time to consolidate each visual stimulus (3000 ms). A post-hoc explanation however is offered by appealing to the speed-accuracy trade-off (see below): subjects tended to perform better when few stimuli were shown [M = 91.90 %, SE = 1.10] than when many stimuli were shown [M = 88.35 %, SE = 2.08]. Manipulating the order for when the object recognition task is given had no significant effect on the speed of responding, suggesting that the task itself was immune to delay - this is not surprising as the object recognition task was deliberately made easy.

The complexity of the stimuli had no effect on how accurate subjects were on the object recognition task. This finding further supports the interpretation mentioned earlier that subjects appear to readily consolidate the visual stimuli into verbal labels, and later rely on verbal representations in completing the recognition task. Varying the quantity of stimuli had a marginal effect on subjects' accuracy, such that subjects tended to perform better when few stimuli were presented than when many stimuli were shown. The greater accuracy for a fewer number of stimuli makes sense since subjects have to hold only 4 items in memory, and not 6, which exceeds their working memory capacities (Awh et al., 2007; Eng et al., 2005). Also, as mentioned earlier, this finding is indicative of the speed-accuracy trade-off: subjects were slower to respond when few stimuli were given, but instead were more accurate. Manipulating the order of presentation of the object recognition task significantly affected subjects mean accuracy, such that their accuracy was severed when the object recognition task occurred after the duration judgment task. Since subjects had to perform the duration judgment task immediately after the elapse of the target stimulus events, it appears that their memories of the objects (whether verbal or visual) had been subjected to memory decay processes, which explains their decline in performance. Finally, an important thing to note is that accuracy scores did not fall under 87 % notwithstanding all the factor manipulations - this further confirms that the object recognition task was relatively easy for all subjects.

Exit-Interview Correlation Analysis For the duration judgment task, none of the questions on the exit-interview correlated with duration reproductions. Most likely, this was due to a lack of construct validity. For the object recognition task, there was a number of significant correlations. The perceived difficulty of the duration judgment task was positively correlated with subjects' reaction times for correct responses, indicating that the more difficult they perceived the duration judgment task to be, the slower their response speed. The amount of effort deployed in completing the experiment negatively correlated with subjects' response speed, whereby the more effort they deployed, the faster their reaction times were. Subjects' level of attentiveness and alertness was negatively correlated with their reaction times, indicating that the more attentive and alert they were, the faster their response speed was. The level of motivation in doing the experiment was negatively correlated with their reaction times, indicating that a greater level of motivation accounted for faster responses. Subject's concentration was marginally (negatively) correlated with their reaction times, such that the more concentrated they were, the higher the tendency to respond faster. Finally, subjects' proclaimed level of anxiety marginally (positively) correlated with their reaction times for correct responses, indicating that the more anxious they are, the greater the tendency to respond slower.

8 General Discussion

The present study dealt with three manipulations that were hypothesized to affect reproduced duration estimates: varying the complexity of stimuli, varying the quantity of stimuli, and the introduction of a secondary task (causing cognitive interference) between the elapse of the target interval and its reproduction. The results showed the following: manipulating the complexity of stimuli presented did not affect later duration reproductions. Varying the quantity of stimuli accounted for shorter duration reproductions when few stimuli (4) were presented, and longer reproductions when many stimuli (6) were presented. Introducing a secondary task that posed both a delay and cognitive interference between the stimulus events to be reproduced and later duration reproductions had a tendency to affect reproduced durations, consequently eliciting shorter duration reproductions without interference than with interference. Lastly, none of these manipulations revealed any interaction effects.

These findings raise a number of questions: How do they relate to the historical ideas of Jean-Marie Guyau and William James, who profoundly speculated on the peculiar nature of subjective time? What do they reveal about the respective paradigms employed in the duration estimation literature? Which of the aforementioned models best explains the present data? What do they reveal about our memory for time as duration? What kind of methodological questions do they surface? Finally, how do they reconcile the temporal perspective aspect of time with the durational aspect of time? Each of these questions is addressed below.

It was mentioned that Guyau (Roeckelein, 2000; Michon, 1988) believed that time itself is not to be found in the universe, but rather in our heads - that is, time is a cognitive manifestation that emerges out of the experiences we undertake in our lives, and memory is the representational vehicle that organizes such experiences. Under this framework, he emphasized certain characteristics of the external world that help shape our passage of time, including the intensity of stimuli, their number, the attention paid to them, the differences between them, and the expectations they evoke from us. These ideas are further complemented by James' (1890) thorough analysis of the plasticity of subjective time - by accentuating our window of duration and pointing out the difference between successive ideas and the idea of succession, how subjective time differs in passing and in retrospect, and how the perceptual features of the environment accommodate such plasticity. Strongly influenced by Guyau's views, Michon (1996, 1990) further posited that time itself is an abstract concept that derives from a basic necessity to stay in tune with an ever-changing world. How can these ideas be operationally realized, if at all?

As motivated earlier, certain factors were manipulated to reveal further clarification and insights into the variability of our temporal experience. These factors were translated into the following: In what way does the complexity of visual objects affect our subjective experience of time? Does disentangling complexity, and manipulating the number of objects in the world alter our temporal experience? Does interfering with memory processes also influence our inference of duration? These questions serve as operational embodiments of Guyaus' and James' insights about the pliant character of time, capable of being imported to the experimental laboratory.

As it turned out, not all these factors complied with the postulated hypotheses - the complexity of visual stimuli fared no different than perceptually impoverished stimuli in influencing subjects' passage of time. This is perhaps an unexpected finding, as common wisdom, by analogy, dictates that looking at a Michelangelo painting diminishes our sense of time, while a watched pot never boils (subjective time expands). However, this may be too far-fetched, as the dynamic world around us necessarily involves motion, and not just static representations - in fact, this was tested by Brown (1995), who showed that stimulus motion lengthened the experience of time, irrespective of their number, as well as by Aubry, Guillaume, Mogicato, Bergeret, and Celsis (2008), who view stimulus complexity as essentially motion complexity. Furthermore, the lack of an effect of stimulus complexity is at odds with the findings of Macar (1996), who found that increasing complexity resulted in shorter duration reproductions.

Nevertheless, by adopting an ecologically-valid approach to complex stimuli (see Fetterman, 1996), it was predicted that the passage of time would be short during the experience itself (in line with the attentional-gate model), but longer when judged later, given that long-term memory processes are being utilized. One possible (post-hoc) explanation is that the simple and the complex stimuli did not sufficiently differ so as to elicit variations in subjective time. An alternative explanation is that the sole preoccupation of subjects was to translate the visual objects into lexical labels, thereafter recalling the lexical items to reproduce duration, completely disregarding the complex features of the retained stimuli.

In varying the quantity of stimuli presented during the target interval, while keeping the physical duration fixed, a significant effect was observed on reproduced durations. This resulted in shorter duration reproductions when few stimuli were shown, as opposed to longer reproductions when many stimuli were shown. As previously mentioned, this effect conflicts with the findings of Predebon (1996a, 1996b), who found that more stimuli resulted in shorter reproductions. Under the tenets of the attentional-gate model (Block & Zakay, 2006), presenting a greater number of stimuli should detract attention away from time, resulting in fewer accumulated pulses, and hence shorter reproductions. This seems to be correct given two modulatory factors: short target intervals ($<$ 2-3 s) and working memory recall. For this experiment, the target interval was 12000 ms, and the memory system called on is long-term memory, in part due to the long target interval used.

One can argue that in fact, this finding better fits the contextual-change model [see Subsection: Clock-free Models), in that a greater number of stimuli results in a greater change in cognitive contexts (Block & Zakay, 1996) to be retrieved. But what constitutes a change in cognitive context? Block and Zakay (1996) have been vague about the conditions that give rise to such changes, phrasing such changes as contextual information that include "environmental, emotional, process, and other similar information" (p. 187). Having said this, it is not that we disagree that changes in cognitive contexts serve as temporal-markers by which events (and event properties) are saliently segmented, but rather that such changes can be further decomposed into constituent parts that might in principle differ from each other. It appears that Ornstein's (1969) storage-size model better explains such a finding [see Subsection: Models of Psychological Time - Clock-free Models], where it is argued that the more stimuli encoded during a time period, the longer the duration estimate; stimuli would accommodate more slots in memory, thereafter a higher number of stimuli would be available for retrieval (see also Hicks et al., 1976).

The introduction of a secondary task that was hypothesized to interfere with subjects' memory for duration marginally affected later reproduced duration estimates, in that subjects had a tendency to give shorter reproductions when there was no interference (standard prospective paradigm), then when they had to perform the secondary task prior to providing duration reproductions. This manipulation essentially brings into question the intricate relationship between memory and time [see Subsection: Four Guyauian Pillars of Time Psychology - The Role of Dynamic Memory]. As mentioned earlier, the secondary task involved object recognition, where subjects had to transform the perceptual visual objects they saw during the target interval into lexical representations in order to respond correctly on the object recognition task. This finding further corroborates the findings of Martínez (1994), despite differences in the implementation of the design [see Section: Discussion]. Under the third hypothesis given, this effect was witnessed due to the following: By performing the object recognition task prior to the duration judgment task, subjects had to have consolidated the visual objects into verbal labels for them to perform well on the object recognition task (which they did; see Subsection: Object Recognition Task). Subsequently, when reproducing the duration of the target interval, subjects would have to actively reconstruct (travel back in memory) their past memories about what they saw, and draw the duration inference then. It remains unclear however whether their subsequent retrieval of duration relied on visual representations consisting of seen objects, or lexical representations consisting of labels for those objects.

With respect to the retrospective paradigm, it was surprising that none of the manipulated factors had an effect. As previously mentioned, the experimental investigation of the retrospective paradigm itself appears to pose a catch-22, due to the following: If a subject should be unaware that she or he will be later asked to provide a duration judgment, then it means the subject, given the deceptive task instructions, believes the task to be about something other than duration estimation. This also means that when the time comes for the subject to provide a retrospective duration estimate, she would have to be given instructions immediately prior to the duration task. Given this, two things might happen: the subject, at least on the first trial (the only trial that can test retrospective duration judgments), might not take the duration judgment task seriously, and therefore respond haphazardly, believing this is not something the experimenter was *seriously* interested in. Alternatively, the subject might not fully understand the instructions given to him the first time - indeed, as was the case for the present study, some subjects who left the first duration judgment task blank later proclaimed that they simply did not understand what was being asked of them to do; after all, why would an experimenter be asking what the duration of the preceding events were only after the start of the experiment, when they could have given instructions about that before the experiment started.

In a related vein, the aforementioned problem may not be unique to the retrospective paradigm. Zakay (1990) makes a distinction between what he called the perceived paradigm and the declared paradigm. The former is what the subject actually believes the experiment to be about, while the latter is what the experimenter would have the subject believe, stated via task instructions. It is not unlikely that even for the prospective paradigm, subjects believed (at least for the first few trials) that the experimental task was nothing more than the object recognition task. Despite that the experiment after the first duration judgment task by necessity becomes prospective, given that the subject now knows duration judgments will be required, there is no a priori reason to assume that the subject is now going to pay attention to time concurrently with the secondary task. This problem of ordering priorities was brought up by Brown (1997), who called this the asymmetric interference effect. In short, it states that there is a general tendency to treat the timing task as *secondary* to a concurrent non-temporal task. From this, the question of interest is as follows: How many trials must a subject undertake before she believed the timing task to be the primary task, and given that there is an answer, how would that affect duration reproductions, given practice (learning) effects?

The forgoing can provide a partial explanation to why all the present duration reproductions were underestimates of physical duration (see also Martínez, 1994 by appeal to the attentional-gate model. Given that subjects treated the non-temporal task (i.e., the object recognition task) as the primary task, their attentional resources were distributed over performing well on the object recognition task, leaving fewer pulses to pass through the attentional gate. This explanation however, seems too simplistic, given what is known about temporal perspective.

Consider the following: the instructions of the present experiment emphasized strictly that subjects should try to respond as fast and as accurately as possible on the object recognition task. While accuracy was mentioned, it was clear that the subjects were being asked to respond as quickly as possible - this becomes evident once subjects embark on the task and realize its simplicity. From this, it is speculated that the reason the subjects tended to give reproduced underestimates irrespective of factor manipulations, is because their temporal perspective (or orientation) had shifted towards a heightened adrenergic response. Two reasons lead us to believe this is so: first, the task instructions emphasized speed[32] far more than accuracy, despite that subjects were told to be accurate. Second, given the time of testing, many of the subjects recruited[33] had consumed at least one or two cups of coffee; the effects of caffeine on duration estimates are well-documented (Gruber & Block, 2005). Caffeine, a ubiquitous psychoactive stimulant, was found to increase attention to an attention-demanding task, via an increase in the pacemaker rate of the internal clock (Gruber & Block, 2005). The attention-increasing effects of caffeine, coupled with the task instructions, seem to provide an adequate explanation of why subjects gave reproduced underestimates, at least at a behavioral level.

Block and Zakay (2006) already speculated on the importance of temporal perspective and how such shifts can affect duration estimates, by appealing to altered states of consciousness and lesion studies. This is further complemented by considering how emotions and impulsivity influence our passage of time (Droit-Volet & Meck, 2007; Angrilli, Cherubini, Pavese, & Manfredini, 1997; Wittman & Paulus, 2007). Up until recently, the duration estimation literature has been predominantly concerned with how cognitive factors shape our experience of time - but it seems that integrated accounts that bind both our cognitive and emotional lives have to be examined in order to appreciate the processes underlying our duration estimates. To provide an example, consider how fearful (arousing) situations lengthen our flow of time (Droit-Volet & Meck, 2007), where it is felt as if everything slows down. This, it is speculated, is just another facet of the complex interplay between our temporal perspective at a given period and subjective time flowing. Whether our temporal perspective is altered due to pharmacologic agents, fear/anxiety, or a manifestation of personality type (see Eisler, 1996, this relationship clearly warrants further investigation.

Further, it is surmised here that the attentional-gate model can be extended to account for a least one aspect of alterations in temporal perspective: the modulation of arousal to non-temporal information. As shown earlier [see Subsection: Clock Models], the pacemaker component can be influenced by arousal level of the organism, whereby more arousal leads to an increase in the pulses emitted by the pacemaker, and if the attentional gate is open wide enough, greater pulse accumulations can be later compared to make a decision. However, arousal in the current model can only modulate the pacemaker for the timing task. It is suggested that arousal due to other factors can also exert

[32] This was even evident from the title of the experiment: "How fast can you recognize an object?"

[33] We actually asked each subject to state how many cups of coffee he or she has a day, but since the effects of caffeine were not within the scope of our hypotheses, the data is not presented here.

inflience on the attentional module via a feedback mechanism, and redirect it to a concurrent non-temporal task, resulting in a decrease in the emission of pulses by the pacemaker. To exemplify, consider the punctuality example provided earlier [see Subsection: Time as Duration]: You are on the side of the road waiting for the late friend, and as a result, you are deeply preoccupied with the passage of time, which seems to be passing by slowly. Suddenly, you witness an explosive head-on collision between two cars. As a result of the crash, your arousal level has shot up (marked by a surge of adrenaline; cf., Maricq & Church, 1983), and you are now only concerned with the car crash, completely forgetting about how late the friend is.

Finally, the question of how time in the seconds-to-minutes range is realized at a neuronal level and what kinds of biological mechanisms subserve such processes warrants some discussion. Earlier [see Subsection: Models of Psychological Time], a brief overview of the different models of (primarily) duration estimation was provided, and it was shown that the attentional-gate model (Block & Zakay, 2006; Block, 2003; Block & Zakay, 1996) provides a plausible cognitive model of how humans encode and retrieve duration. However, the attentional-gate model lacks the necessary neuroscientific support to make it a plausible model at the level of brain processing. In other words, the attentional-gate model fulfills the requirements of the computational and representational/algorithmic level, but not the implementational level (cf., Marr, 1982).

Recently, biologically plausible models of temporal processing that do not posit an internal pacemaker [see Subsection: Clock-Free Models] have been examined (Karmarkar & Buonomano, 2007; Buhusi & Meck, 2005). These so-called intrinsic model of temporal processing (Ivry & Schlerf, 2008) have deviated away from the age-old idea of humans possessing an internal clock, under the assumption that we do not possess a specialized brain system that allows us to represent temporal information; rather, temporal information is inherent in neural dynamics.

As mentioned earlier, the coincidence-detection model (Buhusi & Meck, 2005) has particular appeal. With respect to interval timing in the seconds-to-minutes range, Buhusi and Meck (2005) show that contrary to past findings that implicated a simplistic division between the cerebellum (responsible for millisecond timing) and the basal ganglia (responsible for seconds-to-minutes interval timing) (Ivry & Spencer, 2004; Rao et al., 2001), the basal ganglia do not play an exclusive role in seconds-to-minutes interval processing. Instead, they speculate that the basal ganglia might play a broader role in monitoring the activity of the thalamo-cortico-striatal circuit, and to "act as a coincidence detector that signals particular patterns of activity in working memory" (p. 761). Interval timing, it is claimed, is an emergent property of the thalamo-cortico-striatal loops. Under the coincidence activation model, time keeping processes in the seconds-to-minutes range can be best explained by coincidental activation of the circuit of structures comprising the basal ganglia, the prefrontal cortex, the supplementary motor area, and the posterior parietal cortex[34]. This time-keeping function, moreover, does not solely code for duration, but also for estimation of quantity or numerousity.

[34]No attempt will be made to explain the known functions of each of these structures; the reader is referred to Purves et al. (2004)

The coincidence-detection model relates to Guyau's idea that time (Roeckelein, 2000) is a byproduct of our cognition and that memory is a process that serves to organize and structure our experiences with the world, as well as Michon's (Michon, 1990) claims that the encoding of temporal attributes is a coincidental byproduct (i.e., implicit) of other cognitive abilities. Whether encoding of time at a neurophysiological and neuroanatomical level indeed happens this way is clearly for further research to unveil; however, such a model maintains its appeal in the following way: In engaging with the world, we form memories of our experiences. These experiences comprise a range of cognitive activities, which are subserved by processes in the brain. Later, if the need arises, we can mentally rehearse those memories and inferentially reconstruct the duration (at least in the seconds-to-minutes range) of the experiences by which our memories are about. Under the coincidence-detection model, this would amount to reactivating the consolidated pattern of activity (along with the sequence of pattern-formation encoded) distributed over the thalamo-cortico-striatal circuit.

In other words, it would appear that we can mentally time travel in our memories and replay a sequence of events, whereby duration is inferred from the coincidental patterns of activity (that code for order and content) that occurred during these past events. Clearly, this explanation has its limits; for example, it does not explain how one can be conscious of the passage of time in real-time, unless one can simultaneously read off the patterns of activity in the thalamo-cortico-striatal circuit during the experience and encoding of an event. Nevertheless, it is believed that research aimed at further unraveling the biological mechanisms of interval timing without appealing to clocks (other than the circadian clock) can provide new insights to the long-standing history of time as duration in cognitive psychology as well as psychophysics; as Michon (1988) writes: "...clocks can only keep time, but psychologically there appears to be more to time than just the keeping of it" (p. 174).

9 Conclusions

In this work, attempts have been at unifying the diverse approaches to psychological time. In the first part of this work, this involved the following: a brief exposition of the history of time in cognitive psychology, reviewing the influential ideas of Jean-Marie Guyau, Henri Bergson, and William James. It was advocated that the views of Guyau and James (as well as John Michon) are still valid today, and can benefit the study of time as duration. After, a detailed examination of time understood as duration was provided, that highlighted the rudimentary conceptual and methodological tenets that serve as nourishing preconditions for the experimental study of duration, in cognitive psychology as well as psychophysics. This was followed by a consideration of models of psychological time, that aim to provide an adequate explanation for the plastic character of subjective time. Two broad classes of models were considered: Models that assume an inner clock, and models that do not. It was argued that while clock models (such as the attentional-gate model) provide necessary descriptions at a cognitive level, they are not sufficient to account for lower levels (i.e., neural implementation). Consequently, it was suggested that models with clocks and models without clocks can be understood as complementary alternatives to explaining the phenomenon of subjective time.

The second part of this work comprised a psychophysical study that aimed at bringing some of the historical ideas regarding subjective time to the experimental laboratory. In specific, three manipulations under both the prospective and retrospective paradigm were hypothesized to affect subjects' subsequent duration reproductions: varying the complexity of stimuli, varying their quantity, and the induction of cognitive interference between the elapse of the target interval, and later duration reproductions. It was found that complexity had no effect on duration reproductions, contrary to some past findings. Varying the quantity of stimuli revealed a significant effect on duration reproductions, such that more stimuli resulted in longer duration reproductions. Induction of cognitive interference exhibited a marginally significant effect on subsequent duration reproductions, where duration reproductions tended to be longer after interference than when they immediately followed the elapse of the target interval. Finally, there appeared to be no effect of any of the manipulations on the retrospective paradigm.

Aside from highlighting certain methodological factors concerning the study of duration, it was attempted to bridge the present results to the historical ideas of Guyau and James, as well as shed further light on the explanatory fit of the attentional-gate model. Finally, it was proposed that the coincidence-detection model, a biologically plausible model that works by detecting coincidental activations in patterned brain activity distributed over a set of brain structures could prove fruitful in explaining how timing behavior in the seconds-to-minutes range is encoded and retrieved. Overall, the present work was meant to bring together the scattered approaches to the study of psychological time, and show how each of these approaches can lend explanatory and methodological contributions, with the aim of broadening the horizon of questions that can constructively direct further research on the peculiar character of psychological time.

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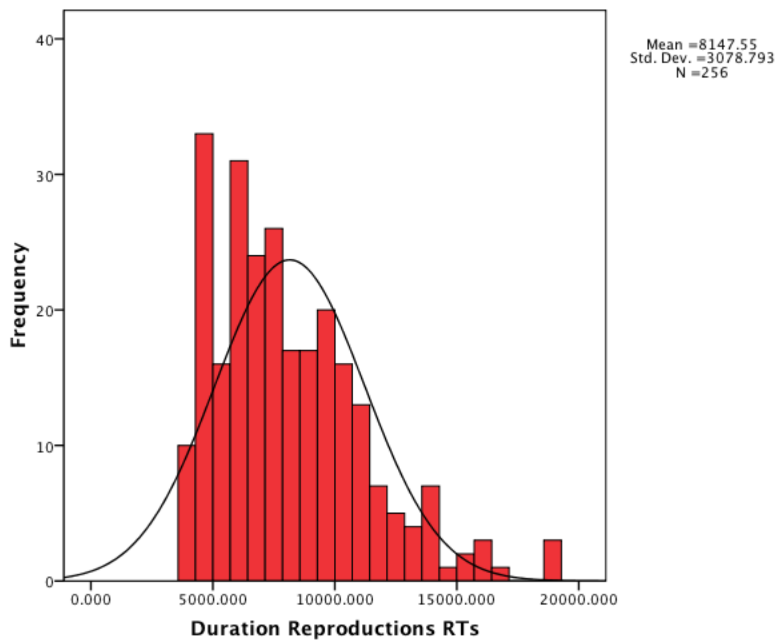
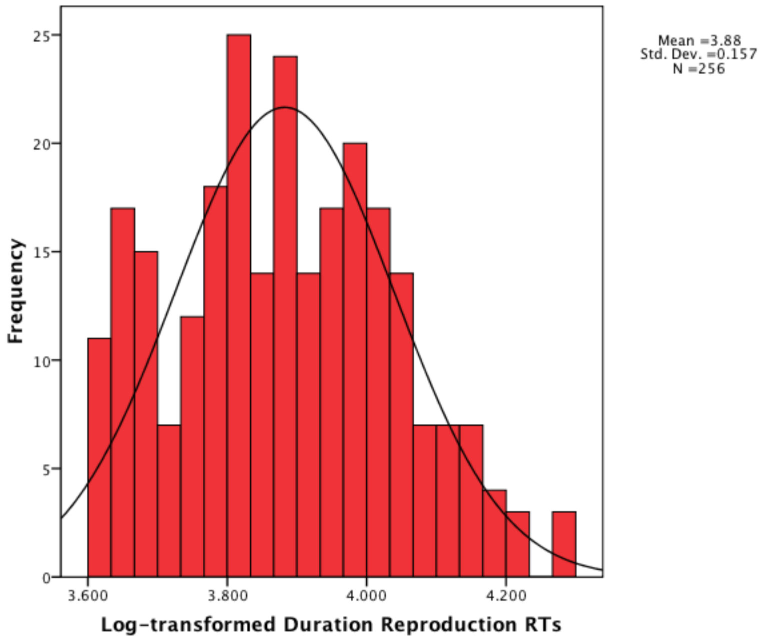
11 Appendix A

Duration Estimation Reaction Times: Post-logarithmic Transformation



Histogram 1: Histogram for object recognition RTs



Histogram 2: Histogram for object recognition RTs after logarithmic transformation

A within-subjects MANOVA with complexity (2 levels: simple and complex), quantity (2 levels: few and many) and delay (2 levels: immediate and delayed) showed that complexity had no significant effect on duration estimates [$F(1, 30) = .025$, $MSE = .000$, $p = .875$], such that participants did not significantly differ in their duration estimates when the complexity of the stimuli presented was simple [$M = 3.876$, $SE = .021$], rather than complex [$M = 3.878$, $SE = .021$]. Varying the quantity of the stimuli presented revealed a significant effect on participants' duration estimates [$F(1, 30) = 18.863$, $MSE = .151$, $p = .000$], such that participants who were presented with few stimuli perceived the target interval as shorter [$M = 3.853$, $SE = .021$] than those who were presented with many stimuli [$M = 3.902$, $SE = .022$]. Manipulating the order by which the duration judgment task is presented had a significant effect on participants' duration estimates [$F(1, 30) = 4.261$, $MSE = .068$, $p = .048$], such that participants perceived the target interval as shorter when the duration judgment task was presented immediately after the picture slideshow [$M = 3.861$, $SE = .022$], than when the duration judgment task was presented after [$M = 3.894$, $SE = .022$]. The mean logarithmically transformed duration estimates for each factor are presented in Figure 1 below.

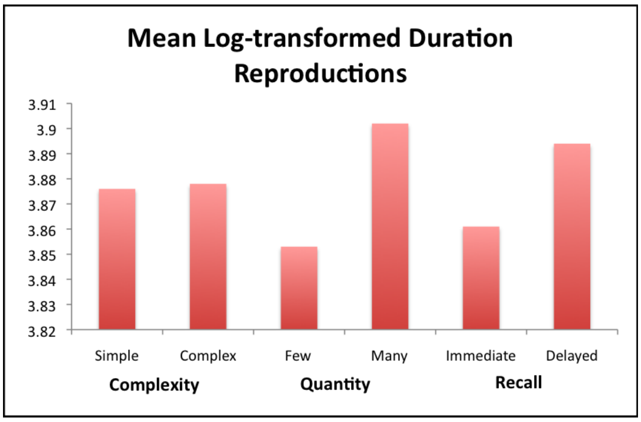
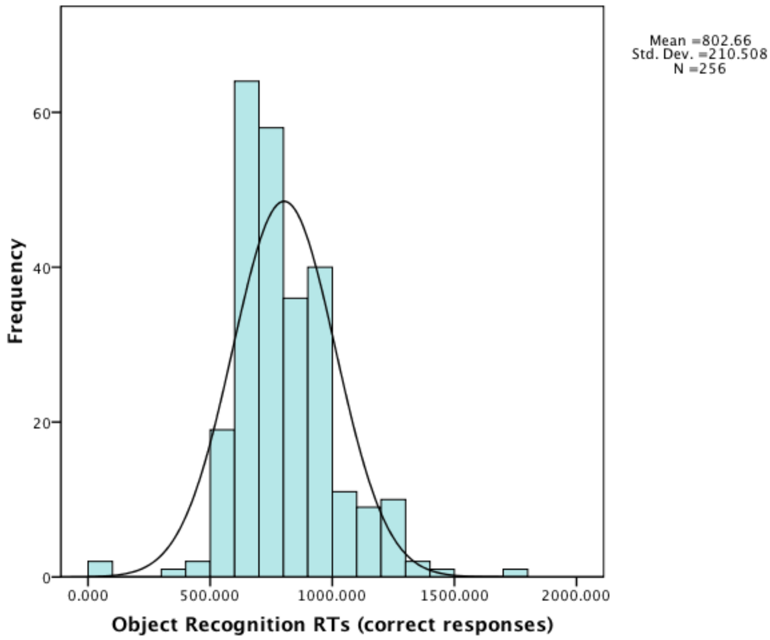


Figure 1: Mean logarithmically transformed duration estimates on the duration judgment task.

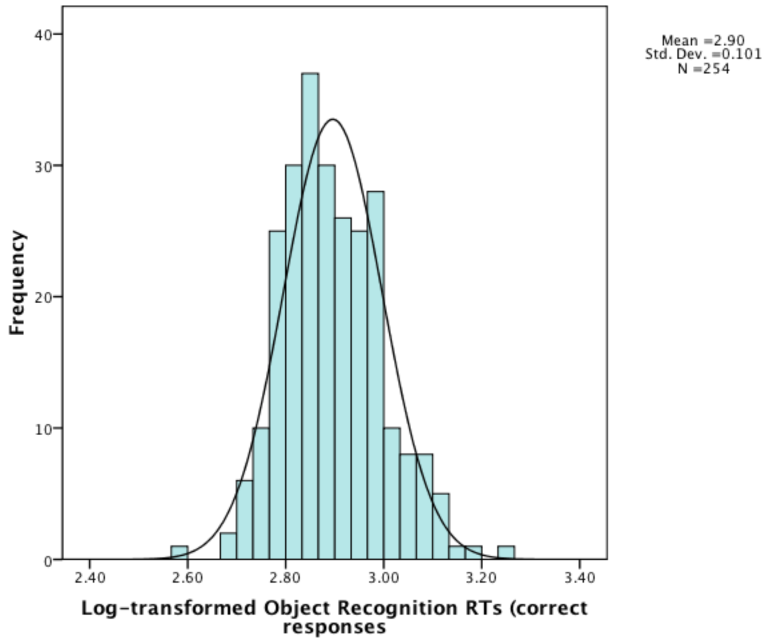
An interaction between stimulus complexity and stimulus quantity had no significant effect on participants' duration estimates [$F(1,\ 30)$ = .015, *MSE* = .000, p = .904]. An interaction between stimulus complexity and order of presentation of the duration judgment task also had no significant effect on duration estimates of the target interval [$F(1,\ 30)$ = .056, *MSE* = .001, p = .814]. The interaction between stimulus quantity and the order of presentation of the duration judgment task likewise did not exhibit a significant effect on participants' duration estimates [$F(1,\ 30)$ = .062, *MSE* = .001, p = .806]. Finally, an interaction between all three factors (complexity, quantity, delay) had no significant effect on duration estimates of the target interval [$F(1,\ 30)$ = .005, *MSE* = 8.536, p = .943].

12 Appendix B

Object Recognition Reaction Times: Post-logarithmic Transformation



Histogram 1: Histogram for object recognition RTs



Histogram 2: Histogram for object recognition RTs after logarithmic transformation

A within-subjects MANOVA with complexity (2 levels: simple and complex), quantity (2 levels: few and many) and delay (2 levels: immediate and delayed) revealed that complexity had no significant effect on logarithmically transformed reaction times for correct responses [$F(1, 30) = .025$, $MSE = .000$, $p = .875$], such that participants did not respond slower in the simple stimuli condition [$M = 2.901$, $SE = .017$] than in the complex stimuli condition [$M = 2.889$, $SE = .014$]. The quantity of stimuli also had no significant effect on reaction times for correct responses [$F(1, 30) = 1.579$, $MSE = .006$, $p = .219$], indicating that subjects did not significantly respond slower when few stimuli were presented [$M = 2.9$, $SE = .016$], than when many stimuli were presented [$M = 2.89$, $SE = .015$]. Presenting the duration estimation task immediately or after the object recognition task had a significant effect on reaction time speed for correct responses [$F(1, 30) = 8.138$, $MSE = .036$, $p = .008$], such that participants responded significantly faster when the duration judgment task was delayed [$M = 2.883$, $SE = .016$], than when it was presented immediately after the picture slideshow [$M = 2.907$, $SE = .015$]. The logarithmically transformed mean reaction times for each of the aforementioned conditions is presented in Figure 1 below.

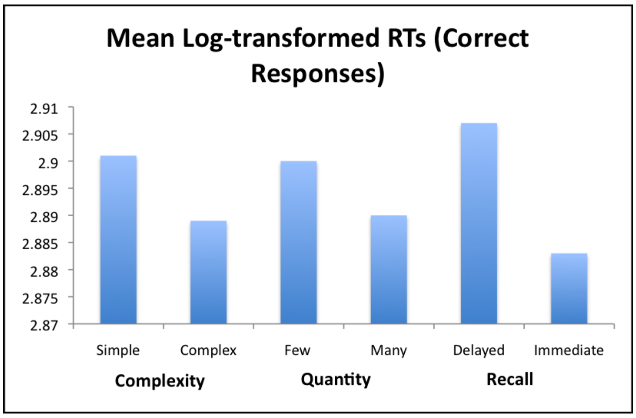


Figure 1: Mean logarithmically transformed reaction times for correct responses on the object recognition task.

An interaction between stimulus complexity and stimulus quantity revealed no significant effect on logarithmically transformed reaction times for correct responses [$F(1, 30) = .074$, $MSE = .000$, $p = .788$]. An interaction between stimulus complexity and order of presentation of the duration judgment task also had no significant effect on speed of responding correctly [$F(1, 30) = 1.135$, $MSE = .003$, $p = .295$]. The interaction between stimulus quantity and order of presentation of the duration judgment task however did have a significant effect on how fast participants responded [$F(1, 30) = 5.521$, $MSE = .021$, $p = .026$]. Finally, an interaction between all three factors (complexity, quantity, delay) had no significant effect on how fast participants responded [$F(1, 30) = .704$, $MSE = .002$, $p = .408$].

13 Appendix C

(a) Simple bed.

(b) Simple lamppost.

Figure 1: Examples of simple stimuli.

(a) Complex bed.

(b) Complex lamppost.

Figure 2: Examples of complex stimuli.

Figure 3: A single frame of the duration cursor.