PROSPECTIVE DURATION JUDGMENTS: THE ROLE OF ATTENTION AND SECONDARY TASKS

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ABSTRACT

PROSPECTIVE DURATION JUDGMENTS: THE ROLE OF ATTENTION AND SECONDARY TASKS

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It is known that concurrent secondary tasks or attentionally salient stimuli shorten reproduced temporal durations. The main aim of this thesis is to use three types of secondary tasks to see their effects on duration judgments. The Attentional Gate Model (Block & Zakay, 2006) served as theoretical background for a series of 4 experiments. There were 2 baseline/control experiments for studying the effect of 2 different and novel secondary tasks which are temporal comparison and non-temporal executive tasks. Three duration lengths (short-moderate-long) were used (15, 30 and 45 sec) that subjects had to reproduce. In Exp-1 (control experiment for Exp-2) subjects had to reproduce almost empty time intervals. Exp-2, which investigated the role of a secondary temporal task, revealed significantly decreased reproduced durations as compared to Exp-1 which is in line with our hypothesis. In Exp-3 (control experiment for Exp-4) subjects carried out a non-temporal/non-executive secondary task. Exp-4, in which a Simon task was used as a non-temporal executive secondary task, resulted in significantly decreased reproduced durations as compared to Exp-3 as well. Moreover, duration length effects were found for all experiments that included an attention consuming secondary tasks (Exp-2-3-4), i.e., longer durations were more underestimated than shorter ones in the presence of attention demanding tasks. We conclude that secondary temporal tasks and even more so executive non-temporal tasks can lead to decreased temporal duration judgements, thus affecting subjects' time perception, in line with the Attentional Gate Model.

Keywords: Prospective Duration Judgments, Attention, Secondary Temporal and Executive Tasks, Attentional Gate Model, Scalar Timing

ÖZ

DENEYİMLENEN ZAMAN ARALIĞI TAHMİNLERİ: DİKKAT VE İKİNCİL GÖREVLERİN ROLÜ

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Yüksek Lisans, Bilişsel Bilimler
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Şubat 2011, 101 sayfa

Deneklere ikinci bir görev yaparken ya da dikkat çekici bir uyarıyla birlikte verilen bir zaman aralığını tekrar üretmeleri istendiğinde, üretilen bu zaman aralıklarının normalden daha kısa olduğu bilinen bir gözlemdir. Bu tezin ana amacı üç değişik ikincil görev kullanarak bunların zaman aralığı tahminleri üzerindeki etkisini gözlemlemek. Attentional Gate Modeli (Block & Zakay, 2006) yapılan dört deney için teorik bir altyapı sağlayacaktır. 15-30 ve 45 saniye olmak üzere üç farklı süre kullanıldı. Deney-1'de (Deney-2 için kontrol) deneklerden neredeyse boş bir zaman aralığını tekrar üretmeleri istendi. İkincil zamansal görevlerin etkisini incelemek için dizayn edilen

Deney-2'de Deney-1'e göre istatistiksel olarak azalmış zaman aralığı tahminleri bulunmuştur. Deney-3'de (Deney-4 için kontrol) denekler zamansal ve yönetimsel (non-executive) olmayan bir görev yapmıştır. Deney-4'de (Simon görevi zamansal olmayan yönetimsel görev olarak kullanılmıştır) Deney-3'e göre azalmış zaman aralığı üretimi gözlenmiştir. Böylelikle, ikincil zamansal görevlerin ve daha da derin bir şekilde ikincil yönetimsel görevlerin azalan zaman aralığı üretimine yol açtıkları ve Attentional Gate Modeli ile uyumlu olarak deneklerin subjektif zaman algılarını etkilediği sonucuna varılmıştır. Dahası, ikincil görevlerin dikkat kaynağı ihtiyacı seviyesine bağlı olarak değişen bir zaman aralığı uzunluğu etkisine rastlanmıştır.

Anahtar Kelimeler: Beklenen zaman aralığı tahminleri, Dikkat, İkincil zamansal ve yönetimsel görevler, Attentional Gate Modeli, Skalar zamanlama

To my sister

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

"Time flies when you are having fun" - this phrase indicates the relativity of our daily time perception (Matell & Meck, 2000). Time experience may even stop or is disrupted anomalously during the usage of some psyhoactive drugs and in some mental diseases such as psychosis (e.g. Saniga, 2003; Dawson, 2005). "Time perception" will be used as a metaphor within the thesis since people have no sensory organs for this purpose and experiencing time can not be called perception literally.

People experience time passing slowly when they are bored or just waiting. They report that a longer duration has passed as compared with objective time units. Boring tasks lead to elongated time experience when there is a lack of information about objective time. On the other hand, when the objective duration is given to the person after the estimated duration, they tend to think their experienced time was short (e.g. they say it seems not much time has passed) since the objective information replaces the subjectively experienced time. This is an informative example that emphasizes the updating mechanism of time perception and the importance of the relation of subjective time experience with objective time. Moreover, we can infer the highly inexact nature of time perception if we consider the dependency of time perception to the information processing level of the brain. For instance, the bored state of the mind can be seen as lack of information processing and this leads to a profound change in our time experience.

Our mind has limited capacity to process information and this brings us to the attentional resource allocation issue. There is much evidence indicating that people can ignore or attend intentionally to some task or another or share their attention between the tasks in duration judgment studies (Casini & Macar, 1997; 1999; Champagne & Fortin, 2008; Macar et al., 1994; Macar, 2002). On the other hand, some tasks including attentionally salient stimuli influence time perception beyond the personal or given strategy. In other words, if the experimenter asks subjects to estimate a duration and concurrently perform a task during that interval, duration judgment is affected parallel with the characteristics of the task. Duration judgment studies are usually based on such dual-task conditions and the task used during an interval has a non-temporal nature (salient stimuli, executive, etc.). More attention demanding non-temporal tasks consume more attentional resources for the correct performance that leads to less available resources for temporal information processing.

One of the most attention demanding tasks are executive tasks. Baddeley (1997) defined executive control within the operational mechanism of working memory. As an example, a conflicting stimulus is a case to be dealt with by the executive control system. We can define "conflict resolution" as the ability to perform a relevant task even if the stimulus is salient and irrelevant for the task perfromance. The “Simon” task is a widely used method to study conflict resolution (Wittfoth et al., 2006). This task is based on the automatic processing of spatial stimuli when stimulus location is irrelevant to the task (Wiegand & Wascher, 2005; 2007a; 2007b). The Simon effect is the difference in reaction time (RT) between incongruent and congruent trials. Congruence and incongruence are defined in terms of the spatial location of a color stimulus, e.g., a red or a blue square on the left or right side of the monitor, and the response towards that stimulus, e.g., to press a key on the left if the stimulus is red and to press a key on the right if the stimulus is blue. Either stimulus and response location coincide (congruence) or differ (incongruence). RTs are typically faster for congruent trials as compared to incongruent ones. Resolving the conflict created by automatic processing of spatial information and performing the correct response consume high amounts of attentional resources. Brown (1997) claimed that a special kind of duration judgments (prospective) and executive functioning share the same attention pool, hence, an executive secondary task will interfere with prospective duration judgment.

One of the aims of this thesis is to show the effects of an executive task on time perception. We prefered the Simon task since it is an executive task with well-known characteristics which, however, has not been used in duration judgment studies before. More crucially we tried to assess the possible effects of a secondary temporal task on duration judgments which has most probably not been studied in the literature before either.

This thesis comprises a series of four experiments. Exp-1 is designed as a control experiment for the second experiment. In this experiment, almost empty intervals were used for the duration judgments. We prefered to say "almost empty intervals" because participants were required to state the serial position of three background colors during the intervals. This is a very easy task and we thought it was better to give subjects a second task even if it was easy for the sake of avoding distraction. In Exp-2, the same design as in the first experiment was used but in this case subjects were asked to compare the relative lengths of the background colors (as a secondary temporal task) during the entire interval. So we could distinguish the effects of attentional resource allocation for a secondary temporal task on the duration judgments of the entire time interval from plain duration judgment.

A non-executive non-temporal secondary task was used in Exp-3. In this task, active motor responses were necessary to perform the task. However, there were no executive requirements. The main aim of this experiment was to act as a baseline for the comparison with Exp-4 which used an executive non-temporal task (Simon task). The same perceptual stimuli were used in Exp-3 and Exp-4 and participants had to respond with the same motor activity. Therefore, we would be able to reveal the effect of conflict resolution requirements in Exp-4 (executive performance) on duration judgments.

The organization of the thesis is as follows: In Chapter 2, an introduction of fundamental characteristics of time perception will be given. The “prospective duration judgment paradigm” and its methods, the dual-task nature of duration estimation studies and the common secondary tasks that are used in time perception studies will be presented briefly. Then, the “Scalar Timing Model” will be investigated as a basic structure for more recent models of time perception. At last, attentional resource allocation and the “Attentional Gate Model” will be explained as the theoretical background of this thesis. The behavioural experiments, their methods, results and the specific discussions for the four experiments will be provided in Chapter 3. In Chapter 4, our experimental results will be discussed in general considering the previous studies. Finally in Chapter 5, we will briefly draw some conclusions from this study.

CHAPTER 2

LITERATURE REVIEW ON PROSPECTIVE DURATION JUDGMENTS

Embodying the external and internal environment requires organisms to represent time intervals on different scales from milliseconds to years. However, the use of temporal information basically operates on a scale of several seconds (Block et al., 1999). Temporal processing has four time scales including microseconds, milliseconds, seconds (minutes/hours) and circadian rhythms. Figure 1 includes three scales of temporal information except the microseconds interval which is mostly about the integration of sounds from the two ears. Circadian rhythms are regulated mostly by hormonal changes affecting the sleep-wake cycle or appetite. Speech, musical activity or motor control which require fine tuning is located on the milliseconds scale and the cerebellum seems to be the center of the fine tuning of temporal information. Interval timing which is the scope of this thesis cover a wider range from seconds to minutes and hours. In this scale, most cognitive functions are performed including a wide variety of behaviour, conscious time estimation, decision making etc. No single theory about timing can cover all these scales for the moment. Timing on the seconds scale mainly corresponds to the “time estimation paradigm” (Buonomano et al., 2002).

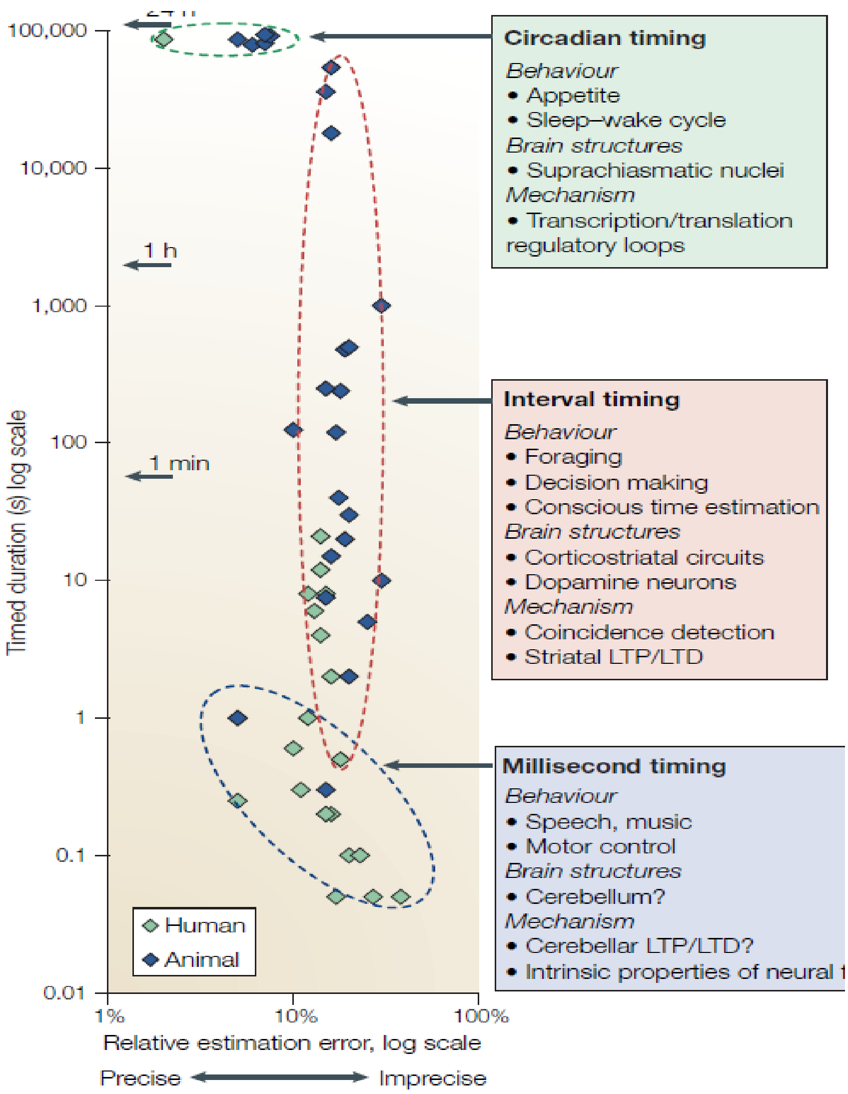

Figure 1. Timescales of temporal processing (Buhusi & Meck, 2005, pp. 756)

The most important distinction is based on the prior knowledge of the subjects about the aim of the experiment which is corresponding to the duration judgment paradigm. A time perception study can be retrospective or prospective according to this distinction. In the prospective paradigm, subjects have prior knowledge that they will be asked about the duration. On the other hand, this information is only given to them after the duration has passed in the retrospective paradigm. Since this study is based on the prospective duration judgment paradigm, we will continue with that topic within the next sections.

2.1. Prospective Duration Judgments

In the prospective paradigm, time estimation is mostly secondary compared to the actual task that is performed, therefore we can call it “implicit” in everyday life (Taatgen et al., 2007). On the other hand, since subjects are informed that they will judge something related to time before the experiment, this paradigm has some explicit aspects as well. In general, the prospective duration judgment paradigm can be seen as a robust way to investigate time perception because secondary (non-temporal) tasks help subjects to attend only partly to the performing of the primary (temporal) tasks which renders them implicit. Primary and secondary tasks are called as such from the perspective of the experimenter in which time estimation is the primary task and the non-temporal task is the secondary task of interest.

Since subjects have prior knowledge that they will judge the passed duration, attentional resources should be divided between non-temporal and temporal information (Gruber & Block, 2005). Attentional regulation would be very crucial because the temporal task is always given together with a secondary non-temporal task (executive or an attentionally salient stimulus). Therefore time estimation in the prospective duration judgment can be called “experienced time”. The dual task condition of the prospective paradigm draws attentional resources from a pool which is open to both temporal and non-temporal tasks (Zakay & Block, 2004).

Prospective remembering occurs mainly in two situations, namely in *time based* and *event based* situations. In event based prospective remembering, subjects should perform an action according to a pre-defined event in the future. The intention to perform a task based on a future event can be self generated or can be given by the experimenter. Moreover, attentional demands of secondary tasks seem not to affect the event based prospective judgments. (Block & Zakay, 2006).

Time based prospective remembering is the main concern of the "attentional gate model" (which is the most recent model regarding attention) because it is more self-initiated and sensitive to the attentional resources. The most common findings about time based propsective remembering are effects of the attentional demands of the secondary task, age and interval length (Block & Zakay, 2006). It is expected that time-based propective remembering is better at short intervals (still on the seconds scale). The reason might be that the time-based paradigm has a tendency to converge with the event-based paradigm as intervals increase.

Secondary non-temporal tasks have an adverse impact on time estimation which increases with task difficulty. Attentional demands of the secondary task influence prospective remembering, that is, subjects underestimate the time duration (Block & Zakay, 2006).

Concepts of temporal relevance and temporal uncertainty determine the mechanism initiated during a task. Temporal relevance corresponds to the importance of time estimation in a certain situation for the optimal behaviour. On the other hand, when there is a situation in which the subjects do not know when the task will end, even approximately, this case refers to high temporal uncertainty. In the light of these concepts, in the presence of high temporal relevance and low temporal uncertainty, time based prospective remembering is initiated. Initiation of one of the two mechanisms depends on how frequently the non-temporal and temporal processor is used (Block & Zakay, 2006). (Figure 2).

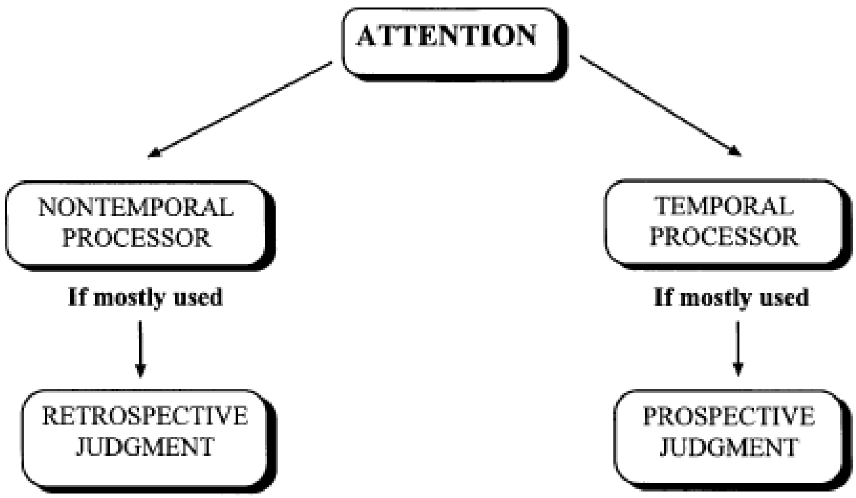

Figure 2. Zakay's 1989 model. (Cassini & Macar, 1999, pp. 75)

The different findings in retrospective and prospective conditions can be explained by the assumption that temporal and non-temporal processors do not work in the same way. Temporal information is processed within a short term memory mechanism, however, the non-temporal processor can transfer the information to long term memory. Therefore, if non-temporal information is prioritized (like in retrospective judgments), temporal information cannot be stored in short term memory and events, contextual changes etc. are used to estimate the durations (Zakay, 1989; Casini & Macar, 1999).

2.2. Duration Judgment Methods

Time perception studies have different categories showing different characteristics such as duration estimation (verbal estimation, production, reproduction, etc.), temporal order, temporal location judgments, stimulus timing, etc. (Block, 2003). Usually these different categories give rise to inconsistent results causing ambiguties within the field (Buonomano et al., 2002). Numerous methods in that field arise as a consequence of the presence of temporal information in almost any activity of human life.

This study is based on the duration estimation paradigm and specifically on the duration reproduction method. All three types of this method will be explained briefly, then in chapter 3, the reason for chosing the reproduction method will be explained.

Subjects label their judgments of passed duration by using numbers in the verbal estimation method (e.g. they state that it seems the duration was 60 sec.). In the production method, people define the onset and the offset of the elapsing time according to the verbally specified duration (e.g. they are asked to start and stop the elapsing time when it seems that 60 sec. passed). In the reproduction method, a target duration is given to subjects and they are asked to reproduce the same duration immediately. There is no requirement of using conventional time units in this method (Block et al., 1999).

2.3. Secondary Tasks in Duration Judgments

Secondary tasks are widely used in psychological studies that are mainly based on the limited attentional source capacity. Basically, it is argued that primary task performance decreases when the cognitive load of the secondary task increases. This observation is based on attentional resource theories (e.g. Kahneman, 1973; Navon & Gopher, 1979; Wickens & Kessel, 1980) in which it is claimed that performance decreases when resources from a common pool of attention must be divided for both tasks (Block et al., 1999).

Using dual task conditions is a basic characteristic of prospective duration judgment studies as well because of the permanent presence of a simultaneous non-temporal task during a timing task (Block & Zakay, 2006). There are always some thoughts or emotions in a subject's mind causing non-temporal processing even if the duration is totally empty or the timing task must be performed by just waiting.

Difficult or attention-demanding tasks on the one hand give rise to an experience of time passing quickly. On the other hand, easy, less attention demanding tasks that require less numbers of stimuli being processed or no active response lead to the opposite effect which is slowing down of time giving rise to an increase of experienced duration (Brown, 2008; Block & Zakay, 1997).

Another notion which is highly relevant for duration judgments is "cognitive load". It can be defined as the amount of information processing demands including attention and working memory. Some perceptual-motor responses which are cognitively driven can be also included within these information processing demands (Block et al., 1999).

There are numerous secondary tasks that are used in time perception studies. For instance, syntactic ambiguity in reading and task switching (Zakay & Block, 2004), the Stroop task and its variations (Zakay, 1993), the addition task (Taatgen et al., 2007), picture naming (Gautier & Droit-Volet, 2002), driving a car in a simulator or watching a videotape of a car (Gruber & Block, 2005), working memory span test (Ulbrich et al., 2006), the randomization task (Brown, 2006), categorizing words (Macar, 1996), visual search (Brown, 1997), and the card sorting task (Zakay & Shub, 1998).

Tasks should be distinguished according to their executive requirements because calling them difficult or easy seems to be arbitrary most of the time. For instance, picture naming, driving a car in a simulator or the addition task should be called "non-temporal, non-executive" tasks. These tasks require varying amounts of attentional resource allocation, but common to all of them is their lack of executive necessity. There is no conflict or strategy requirement included within the tasks. That means, there is no interference while performing non-temporal non-executive tasks. The only interference exists between the secondary task and the duration judgment task. On the other hand, inherently in the Stroop task or the randomization task there is an interference to be solved or a strategy requirement, respectively, that needs an executive control mechanism. These tasks are called "non-temporal executive tasks" and they consume more attentional resources due to their executive nature. Therefore, it is expected that executive tasks change the duration judgments more profoundly than non-executive tasks. This is because people will use more attentional resources to perform the secondary executive tasks so that fewer resources are available for the timing task.

The Simon task is one of the mostly used tasks to study cognitive control. The spatial position of the stimulus activates a quick response tendency to respond to the stimulus location even if the subjects should respond considering the shape, color etc. of the stimulus. Interference occurs at the response selection part of the information processing in a Simon task. The difference in reaction times between incongruent (when the irrelevant spatial and the relevant dimension of the stimulus do not overlap) and congruent (when they overlap) trials is called "Simon effect". The Simon effect is a very strong indicator of the presence of interference. The conflict that is present in incongruent cases should be resolved by cognitive control. Response selection in conflicting situations should be the concern of the executive control mechanism. Therefore, the Simon task is a very appropriate task to increase the amount of attentional resources allocated to the secondary non-temporal task within a duration estimation study.

2.4. Attention and Time Perception

Attentional resource allocation is a flexible, continuous process reflecting the intensity of temporal relevance and temporal uncertainty (see 2.1) at a specific moment. And it is executive functions that control subjects' resource allocation strategy (Block & Zakay, 2006). Duration judgments require sustained attention as opposed to visual or auditory stimuli which do not involve long-standing attentional requirements (Lejeune, 1998). This fact is an indicator of the importance of the attentional resource allocation strategy and executive control mechanism.

Many studies indicate that duration judgments that are performed with a concurrent non-temporal task are shorter, more variable and more inaccurate (Brown & Bennett, 2002). It is widely accepted that there is a competetion between temporal and non-temporal features of a stimulus for attentional resources since they share a limited common pool (e.g. Brown, 1985; Brown & Boltz, 2002; Block & Zakay, 2006; Block et al., 1999; Casini & Macar, 1999; Zakay & Block, 2004; Zakay, 1993).

The central role of attention in temporal experience is not captured by the early time perception models. The "Scalar Timing Model" is one of the theories which does not give a role to attention in time experience. It was mostly built upon animal timing studies and psychophysics, but even in the models that are based on the Scalar Timing Model and that were extended to human time perception, the role of attention was ignored until recent years.

2.5. Models of Time Perception

The topic of time estimation, as many topics in cognitive science, can be investigated using psychological or neuroscientific models. In this part of the review, we will focus on time perception models and leave the neural mechanisms for the next section.

A great variety of psychological models has been proposed, but "internal clock models" constitute the basic structure (Matell & Meck, 2000). We will introduce internal clock models since these models (with all its variation) have quite good explanatory power in many duration judgment studies and can explain the attentional regulation of timing.

Internal clock models basically come in three different variants depending on their clock stage: pacemaker-accumulator models, process-decay models, and oscillator/coincidence detection models. We will give only some brief information for process-decay and oscillator/coincidence detection models about which mechanisms lead to the clock stage and scalar property. Our main concern is the scalar timing model based on the pacemaker-accumulator structure.

For instance, the role of the clock is achieved by memory decay (habituation in the *spectral timing* version of the process-decay model) and the scalar property comes from the decay curve in the *multiple time scales* version of the *process-decay* model (Matell & Meck, 2000). In these models, continuous time passage is achieved by the memory trace of neuronal activity (Lewis & Miall, 2006). Moreover, there are two types of *oscillator/coincidence detection* models: *multiple oscillator* and *beat frequency* models in which a scalar property is built on the oscillation periods and the coincidental firing of neurons at the criterion time, respectively (Matell & Meck, 2000).

Our study is based on attentional resource allocation and pacemaker-accumulator models which have a quite appropriate structure for our purpose. We will introduce the Scalar Timing Model (Gibbon, 1977; Gibbon et al., 1984a) in detail since it is the first substantial model within the historical development of timing models to explain some fundamental properties of timing. Then the Attentional Gate Model which is a modified version of the first internal clock models will be introduced in order to understand the attentional regulation of time perception.

2.5.1 The Scalar Timing Model

Scalar timing models which are based on animal studies were dominating models to explain especially interval timing for a long time. These models assume an internal clock mechanism (Block, 2003). Scalar Expectancy Theory (SET) (Gibbon, 1977) is an information processing theory that is based on a pacemaker-accumulator mechanism which functions as a clock (Graf & Grondin, 2006). Three processes are involved in the model: a pacemaker-accumulator, a memory, and a decision process (Figure 3).

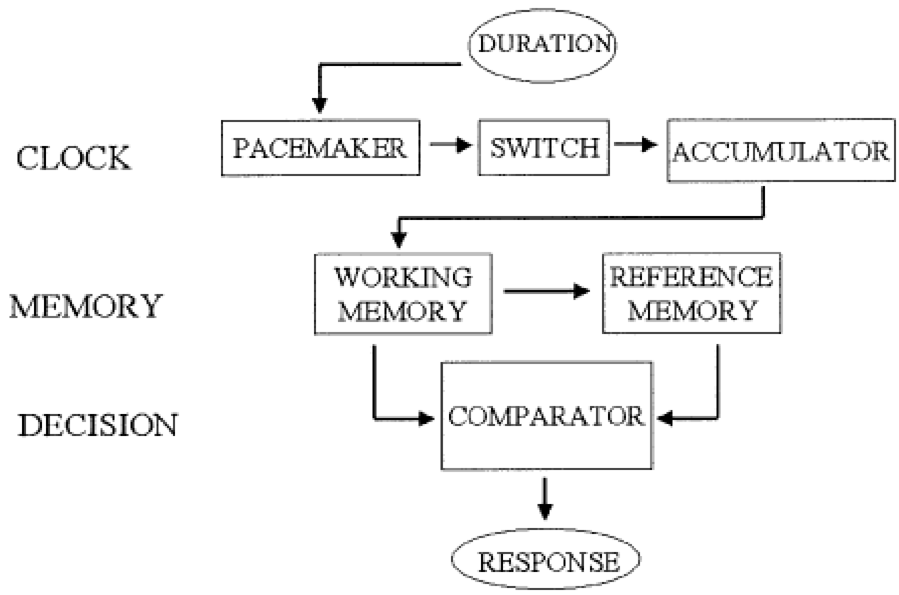

Figure 3. A typical scalar-timing model**.** (Allan, 1998, p.2)

The pacemaker produces pulses continuously with some distribution. When the switch (part of the pacemaker-accumulator module) closes pulses can reach the accumulator. The switch can be closed or opened according to the onset and offset of the stimulus (Church, 2003). The pacemaker-accumulator can be combined with short term memory (STM) in some variations of the model. Long term memory is used as a reference memory with its collection of many temporal intervals (Wearden, 1999). The decision process is done according to three inputs: the present time which is found at the accumulator, a remembered time from the memory part of the system, and a threshold chosen randomly from a distribution of samples. A decision of making a response or not is based on the ratio rule and threshold (Church, 2003). During the reproduction of an interval of equal length, a start signal is sent to the switch and pulses are counted until the approximately same number of pulses has been reached as were stored in STM.

It is proposed in SET that estimations produced by subjects converge on their actual durations after several temporal judgments (Graf & Grondin, 2006). Duration judgments differ from one trial to another (variance) which gives the *scalar property* itself. The scalar property is a consequence of the constant *coefficient of variation* (CV) (SD-variance/mean) as judged intervals vary. This in turn means variance should increase with increasing estimated durations (Wearden, 1999) (Figure 4). The constant CV is called "Weber fraction" in psychophysics (Graf & Grondin, 2006).

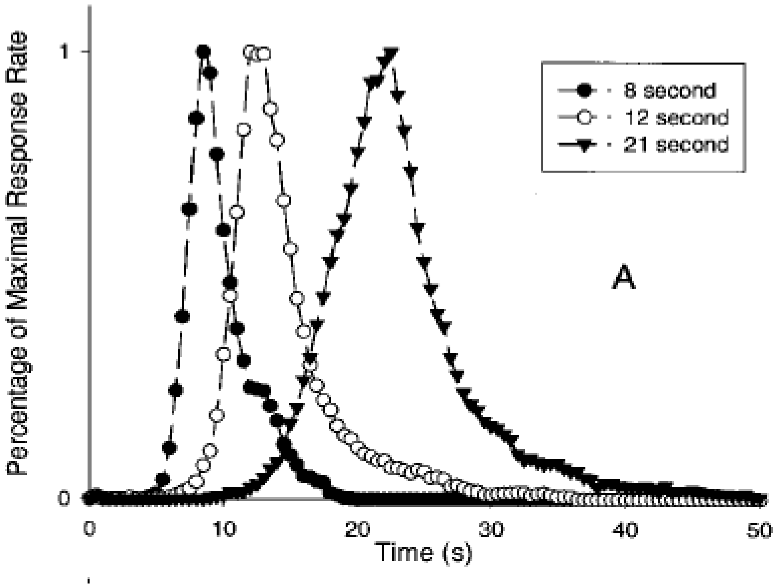

Figure 4. Scalar Property of Interval Timing

(Matell & Meck, 2000, pp. 95)

Variance seen in behavioral data (estimations) can be due to variance in any part of the system: in the pacemaker-accumulator, memory or decision part (Wearden, 1999). The source of error in estimations of time could be the (un)reliability of the pacemaker which means the pulse maker device's response rate could be constant or variable in different periods of intervals (Graf & Grondin, 2006). Indeed, the pacemaker tends to produce non-scalar variance since pulses are emitted at a constant rate but the time between pulses varies randomly. Therefore the coefficient of variation (CV) calculated with SD would decrease as estimated durations increase. However, variance grows in parallel with the mean (Wearden, 1999).

There are many points, for instance lack of the attentional regulation on timing, which cannot be explained with scalar timing models. Moreover, animal studies are generally based on only a few typical experimental methods including duration judgments of a single stimulus or an interval between two stimuli. Due to this restriction, other features of time perception may have been ignored (Block, 2003).

2.5.2. Attentional Gate Model

In this part, the attentional gate model will be introduced as an account for time-based prospective remembering. The operating mechanism of the model is explained as follows:

a) Signals at a constant rate are emitted by the pacemaker as in the scalar timing models. Synchronized neural firings can be the neural counterpart for this function. Arousal level can affect pulse emitting and change the rate slightly.

b) Executive functioning controls the attentional resource allocation and may be used either for timing or for other tasks. This is achieved by the attentional gate within the model. If more resources are allocated to timing, more pulses pass through the gate since it is open wider now.

c) When the gate is open longer, more signals reach the accumulator of the model. Concurrent non-temporal secondary tasks consume some attentional resources and leave fewer resources for timing.

d) There is a switch between the gate and the accumulator defining the onset and the offset of the duration to be estimated. When a person sees the cue for the beginning of the interval, the switch opens and the signal stream flows from pacemaker to accumulator.

e) At the end of the target duration the switch is closed and signal storage in the accumulator is terminated. The number of signals, which is a kind of representation, is transferred to working memory.

f) In case of reproduction of an interval, the representation stored in working memory can be compared with a reference memory which is encoded in long term memory. Cognitive comparison continues until a match is obtained between the representation in working memory and the reference memory encoded in long term memory. Then the intended response as decided by the cognitive comparison process is retrieved from long term memory and the person makes the response (Figure 5) (Block & Zakay, 2006).

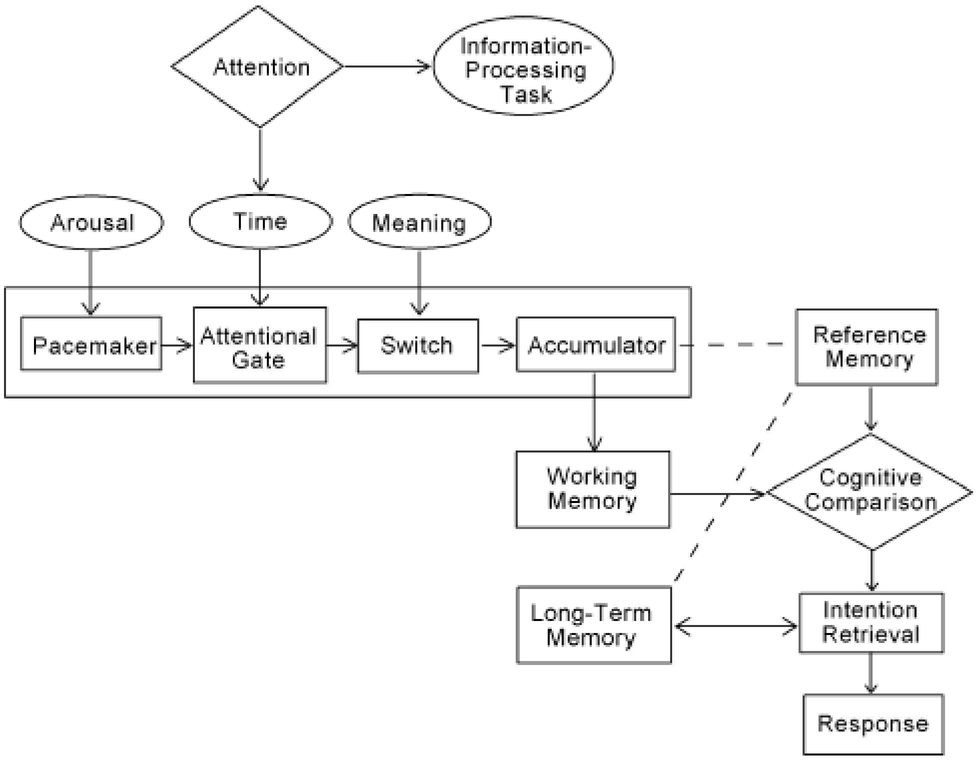

Figure 5. Attentional Gate Model. Block &Zakay (2006, pp. 32).

Attentional processing explanations can be divided into two general classes: filter and capacity theories. The term "Attentional resource allocation" is used within the capacity theories which are based on the idea of attentional processing limitations (Lejeune, 1998). There are some controversies about the necessity of a gate (Lejeune, 1998, 2000; Zakay, 2000); however, the attentional gate model has its value by incorporating attention formally into pacemaker-accumulator models (Brown, 2008).

In conclusion, the attentional gate model is an appropriate model to explain duration judgments and is supported by many experimental studies. On the other hand, all aspects of time estimation should also be supported by neuroscientific findings (see Ivry et al., 2008).

2.6. Neural Correlates of Cognitive Models of Timing

Recent neuroscientific findings indicate a distributed representation for timing in the brain. This is rather an expected result considering the different scales of the temporal processing. Pacemaker accumulator models have been constructed in order to explain processes on the seconds-minute scale and there are many pieces of evidence supporting the biological plausibility of these models (Buhusi & Meck, 2005). For instance, Bendixen et al. (2005) found that the amplitude change of auditory event related potentials indicate more pulses give rise to the elongated experience of time in line with pacemaker-accumulator timing models. Several brain regions including dorsolateral prefrontal cortex (DLPFC), inferior prefrontal cortex (IFC), anterior cingulate gyrus (ACG), supplementary motor area (SMA), basal ganglia and cerebellum seem to be active during motor timing and duration estimation (Rubia & Smith, 2004). There seem to be broadly two circuits of timing: a system involving the cerebellum which is responsible for discontinuous events in the milliseconds range and another mechanism involving the basal ganglia and related cortico-striatal regions dealing with continuous events using cognitive control such as attention (Buhusi & Meck, 2005).

In the attentional gate model, signals are produced by a pacemaker at a constant rate. The neural counterpart of this module may be the synchronized neural firings of cell assemblies in the brain. Moreover, the key component of the model, the attentional gate, may in all likelihood correspond to the anterior cingulate gyrus which is responsible for executive control of attention (Block&Zakay, 2006).

As an early implementation of pacemaker-accumulator models, Gibbon et al. (1984) suggested the role of the dopaminergic system and acetylcholine activity (Figure 6). Specifically, it is observed that dopaminergic drugs, let's say antagonists, decelerate the internal clock speed and cholinergic drugs affect the memory storage by changing the cholinergic activity in the frontal regions of the brain. For instance, degeneration of the nigrostriatal dopaminergic projections (e.g. substantia nigra pars compacta) in Parkinson's disease give rise to disruption of the interval timing (Buhusi & Meck, 2005).

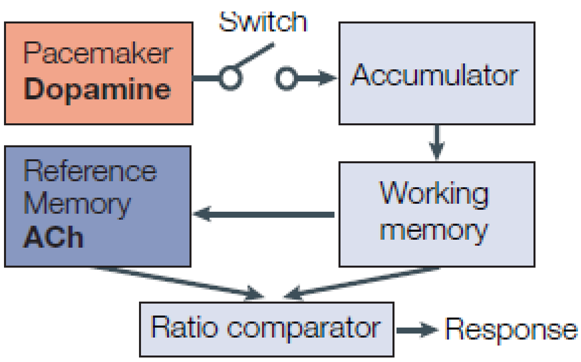

Figure 6. Implemantation of scalar expectancy theory (Gibbon et al., 1984) in Buhusi & Meck, 2005.

The coincidence-detection model constructed on a neural basis and the pacemaker–accumulator model providig behavioural explanations for timing judgments of real subjects seem to be two sides of the same coin (Buhusi & Meck, 2005). Matell & Meck (2000) suggested a model by integrating Miall's beat frequency model (Phillips et al., 1993) and Houk's

coincidence detection explanation (1995) based on the function of the striatum. In this model, syncronized activity which is triggered by the onset of a stimulus has a variable number of oscillatory periods. Striatal neurons are trained with long term potentiation/depression to detect coincidental activity of a set of cortical neurons. The output of striatal neurons and basal ganglia neurons (globus pallidus, subthalamic nuclei and substantia nigra pars reticulata) goes to the thalamus from where a behavioral response is invoked (Matell & Meck, 2000). Dopaminergic activity via substantia nigra pars compacta to the striatal spiny neurons has its place in Matell&Meck's model as well (Figure
7).

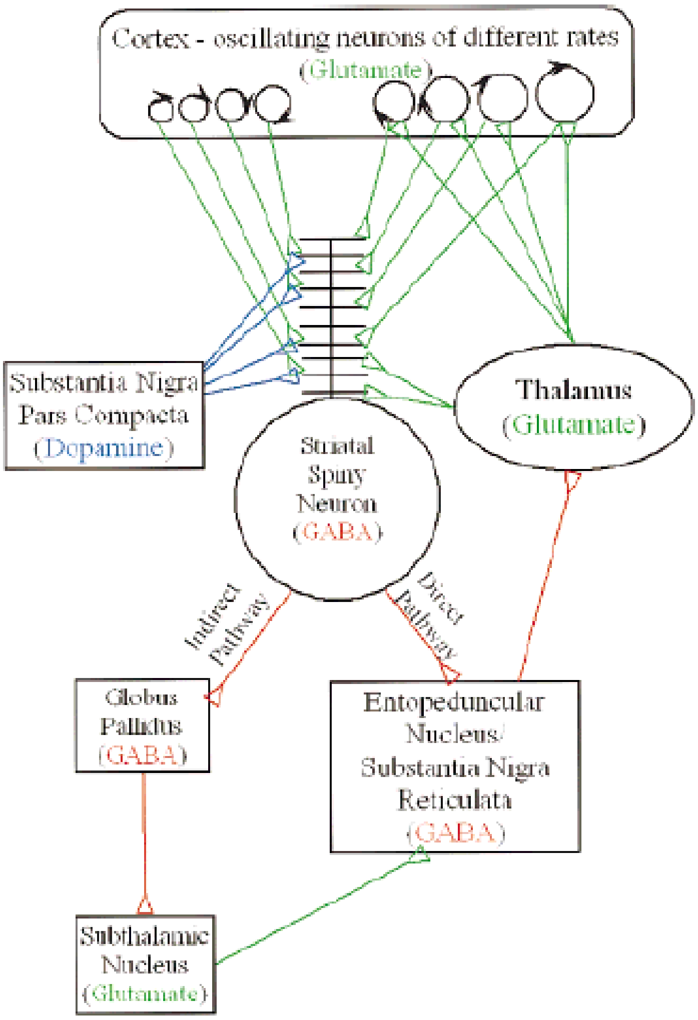

Figure 7. Matell & Meck (2000, pp. 99) model of timing including cortex oscillating neurons, striatum and basal ganglia

On the whole, cognitive models that are based on a pacemaker-accumulator mechanism seem to be biologically plausible. Although cognitive models propose a pacemaker module that seems to be a single localized brain region, it is already not an expected result as the examples above show that there must be many distinct regions (e.g. distributed dopaminergic activity) implementing a single pacemaker module of the cognitive models. On the other hand, these neural models do not include specifically the anterior cingulate gyrus which is the most probable candidate to implement the gate component of the Attentional Gate Model. Since our study is mostly based on the executive control of the attentional resource allocation, it would be better to introduce a model including anterior cingulate cortex, if there is any. However, the core structure of the model (pacemaker-accumulator), which we used as a theoretical background in our study, seems to be quite biologically plausible.

CHAPTER 3

BEHAVIORAL EXPERIMENTS

Time perception is not a single centered mechanism and there are many categorizations based on the duration scales and estimation types. Duration judgement experiments are usually designed as dual tasks: the primary goal is the time estimation and a secondary task is used to manipulate the duration judgement. But secondary tasks are not revealed to the subjects as such during the experiment; rather, they are asked to divide their attention equally between the tasks. We prefered multi-seconds scales (15-30-45 sec) and the duration reproduction method for all experiments due to the nature of our secondary tasks. It was necessary to choose long enough durations to be able to observe effects of executive tasks on time estimation since we thought the Simon task can be an effective distractor when there are enough Simon task trials in one duration reproduction trial. Furthermore, we avoid time production and verbal estimation methods due to the presence of verbal inputs (time production) and outputs (verbal estimation) which is thought to be an additional confounding factor .

There was no attention demanding secondary task in Exp-1 and it was a control study for all experiments, especially for Exp-2. On the other hand, Exp-2 includes a goal directed secondary task. It was a temporal task like the primary duration judgment task. Exp-3 was designed for the sake of comparison with Exp-4. In this experiment, the secondary task was motor responses according to rectangles on the right or left of the screen lacking any strategy or conflict. The most attention consuming secondary task was the Simon task in Exp-4. It requires executive functioning which is thought to lead to attentional resource allocation for the non-temporal processor instead of the temporal processor. On the other hand, it is already possible to compare the results of those four experiments despite the between subject design of analysis since they had all the same within subject variables which are the judgments of the same three duration lengths.

General Hypotheses:

1. We expect to find an increasing trend in variance of time estimation with increasing durations from 15 sec to 45 sec and stable coefficient of variation for all durations in conformance with the predictions of scalar timing theory.
2. If the Attentional Gate Model (Block & Zakay, 2006) of time perception is true, we should find underestimations for the experiments including a secondary executive (Simon Task-Exp-4) and a secondary temporal task (Exp-2) as compared to their control experiments, namely Exp-3 and Exp-1, respectively.
3. It is expected to find a difference in duration lengths of the estimations in Exp-2 (secondary temporal task) and Exp-4 (secondary executive task). In Exp-4, the secondary Simon task includes a conflict resolution which should be performed by non-temporal processors as opposed to the temporal comparison task in Exp-2. The modality difference between primary task (duration estimation) and

secondary task (executive task) should create a further shift in attentionl allocation to the secondary task in Exp-4. On the other hand, some attentional resources allocated for the secondary temporal task in Exp-2 may still be used for duration estimation since both tasks share the common mechanism of the temporal processor. Therefore we expect to find more underestimated durations in Exp-4 than in Exp-2.

Procedures

Experiments were run in a silent room in front of a CRT monitor at a comfortable distance to the subjects. Experiments were conducted with E-prime 1.2. They started with a practice phase including one trial from each duration length, namely short, medium and long. However, these durations (12-25-37 sec) were not the same durations that were used during the experimental sessions. There were 5 trials for each length of duration (15-30-45 sec) that were randomly presented to the subject. The experimenter stayed with the participants during the practice phase to make sure that they learned the rules correctly but left the room when the test session started. All sessions including the practice phase took 10-15 min. All participants were instructed not to count loudly or silently during their performance.

3.1. EXPERIMENT 1: EMPTY TIME- CONTROL EXPERIMENT

In this experiment, attentional resources have to be divided between non-temporal and temporal processors during performance. It is expected that there will be less attentional resources available for the temporal processor in the presence of high demands from the non-temporal processor due to the limited common resources (Block & Zakay, 2006; Block, 2003; Burle & Casini, 2001; Casini & Macar, 1997; 1999; Zakay & Block, 2004; Brown, 2006; Zakay & Block, 1997). Experiment 1 was thought to be a baseline for all the following experiments and especially for Exp-2. Durations were not presented as totally empty time intervals which may give rise to boredom effects. Instead participants just had to remember the sequence of three different background colors, blue, red, and yellow. Ignoring boredom as a factor in such experiments may give rise to problems. Although it may not be considered as a challenging task, sequencing the colors preoccupy subjects in the experiment. Indeed, time perception and boredom experience have common components (Danckert & Allman, 2005). Moreover, we kept the number of experimental trials to 15 in order not to cause any distraction at the end of the experiment due to possible boredom. Five trials per duration is in line with the number used in the literature (e.g. Danckert & Allman, 2005, Gautier & Droit-Volet, 2002).

Specific Hypothesis

Reproduced durations in Exp-1 should be the longest within all of the experiments. Explanation: In the absence of any attention-demanding task, we can expect elongated reproductions since all of the attentional resources can be allocated to the temporal processor which results in experiencing the durations as longer than in all experiments. This setting may give us more accurate estimations with respect to objective duration lengths. Note that duration reproductions in general give rise to underestimations (e.g. Block & Zakay, 2006; Block, 2003; Casini & Macar, 1999; Zakay & Block, 2004) and any elongation in reproductions shifts estimations closer to the objective lengths.

3.1.1. Method:

Participants

A total number of 11 subjects (5 females / 6 males) participated voluntarily in this study. Their mean age was 21.09 years (SD= 2.26). All of them had normal or corrected-to-normal vision.

Procedure

The general set-up was as follows: A black square was in the center of the screen and background color changed randomly between white, yellow, red and blue. Since a white background was used as a default here as well as in Exp-2 (where participants needed to pay attention to durations of the other three colors), they were asked to write down the sequence of the other background colors (yellow, red, and blue) on a sheet of paper after completing the study phase (see Appendix A). Then an instruction page was shown that informed the subjects to continue with the duration reproduction part of the trial. The purpose of this instruction page was to let subjects start their reproduction of the durations themselves. The interval reproduction part could be started immediately after a given trial since participants learned what was written on the instruction page in the practice phase and passed it quickly in the experimental session. After the instruction page, the same black square was seen on the screen to let them know the clock is ticking. Then they had to press a defined key (space bar) to stop their estimation for the most recent entire duration they had performed in the sequencing task (Figure 8).

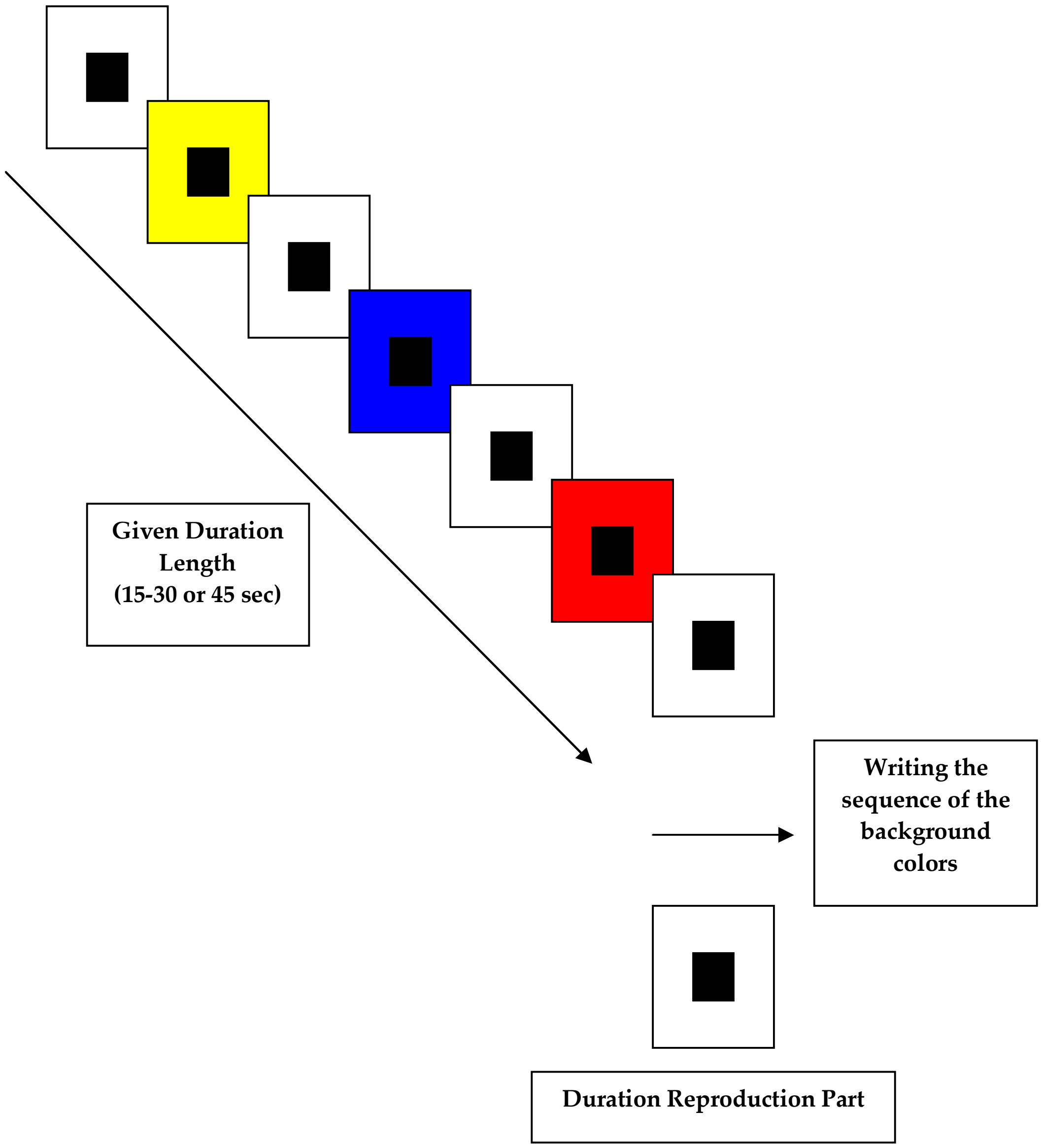

Figure 8. Flow of an experiment trial (Exp-1)

3.1.2. Results

A Repeated measures ANOVA with the three duration levels as within-subjects factor was conducted to reveal whether there was a difference between estimations of different lengths of durations (Table 1).

Table 1. Judgments for three levels of duration in time estimation task without a secondary task

	Durations		
	15 sec	**30 sec**	**45 sec**
Raw Estimates (SD)	15.7 (6.9)	30.4 (10.3)	42.1 (11.6)
Difference Scores	0.7	0.4	2.9
Ratio (Judgments/ActualDuration)	1.05	1.01	0.93
Absolute Errors (sec)	3.6	6.1	7.2
Coefficient of Variation	1.7	1.5	1.6

The ratios of participants' reproductions and actual durations were used for the analysis which revealed no significant main effect for the duration length. ($F(2, 20) = 1.497$, $p > .05$) (Figure 9).

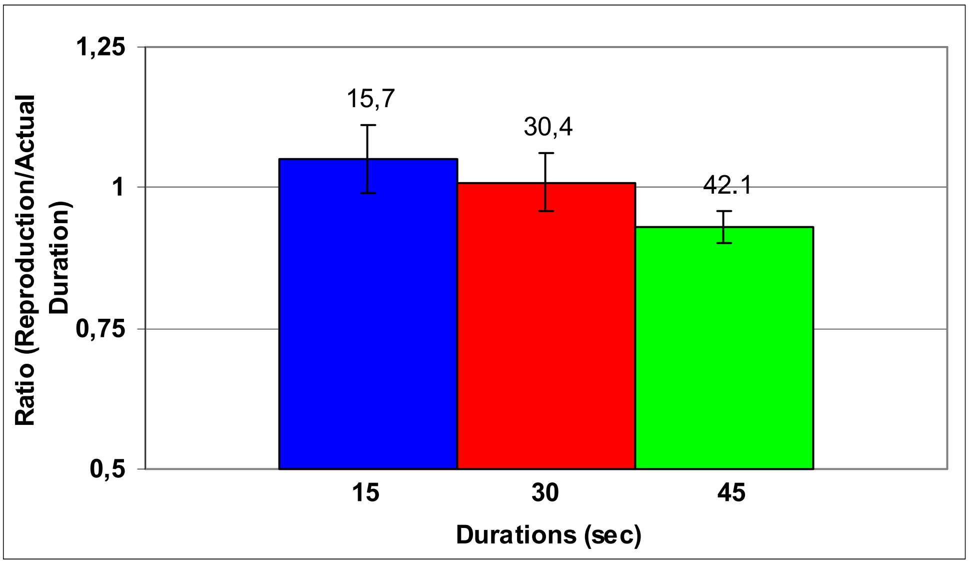

Figure 9. Effect of duration length on the ratio of the reproductions / actual duration; values on the bars are raw reproductions for the three durations; error bars indicate SE (Exp-1)

Difference scores were calculated by substracting each reproduction from its actual duration. Negative outcomes point to overestimation and positive ones were the signs to underestimation. A binomial (Sign) Test was conducted to see whether there was a tendency of underestimation or overestimation for different durations. The number of underestimated trials (36) for the longest duration (45 sec) was significantly higher than the number of overestimated trials (19) ($Z = 2.24$, $p < .05$). There were no significant differences between number of understimated and overestimated trials for the other durations ($p > .05$) (Figure 10).

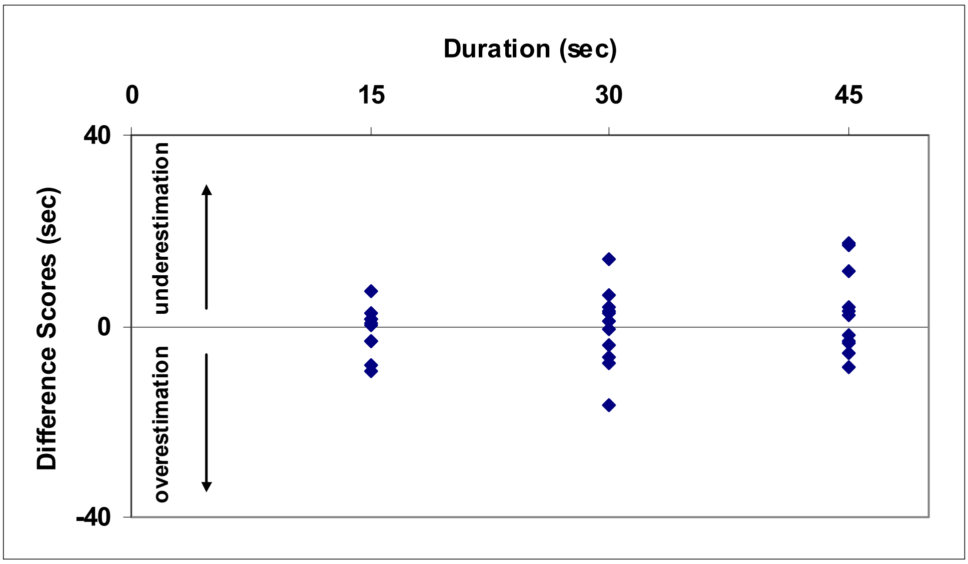

Figure 10. Difference Scores of each subject for durations (Exp-1)

Absolute errors were calculated by substracting each reproduced duration from the actual duration ignoring the sign of the result. Then mean absolute errors were divided by the variance of the corresponding duration in order to obtain meaningful results in a within subject design ANOVA with three levels of duration. Otherwise, since variances increase with increasing durations, a significant duration effect for absolute errors would not produce reliable results for the comparison of durations. A Repeated Measures ANOVA revealed no significant effect of duration length on absolute errors ($F(2, 20) = 2.451$; $p > .05$) which suggests that all durations were judged similarly with respect to accuracy.

A Repeated ANOVA was designed with three levels of duration by using individual variances to reveal the pattern of increasing variance from shorter to longer duration. Although there was no significant overall duration main effect ($F(2, 20) = 1.972$; $p > .05$), a Helmert contrast revealed a significant variance difference between the first level (shortest duration) and the two remaining durations ($F (1,10) = 4.803$, $MSE= 2380$, $\eta_p^2 = .324$, $p < .05$) (see Figure 11 for group mean variances).

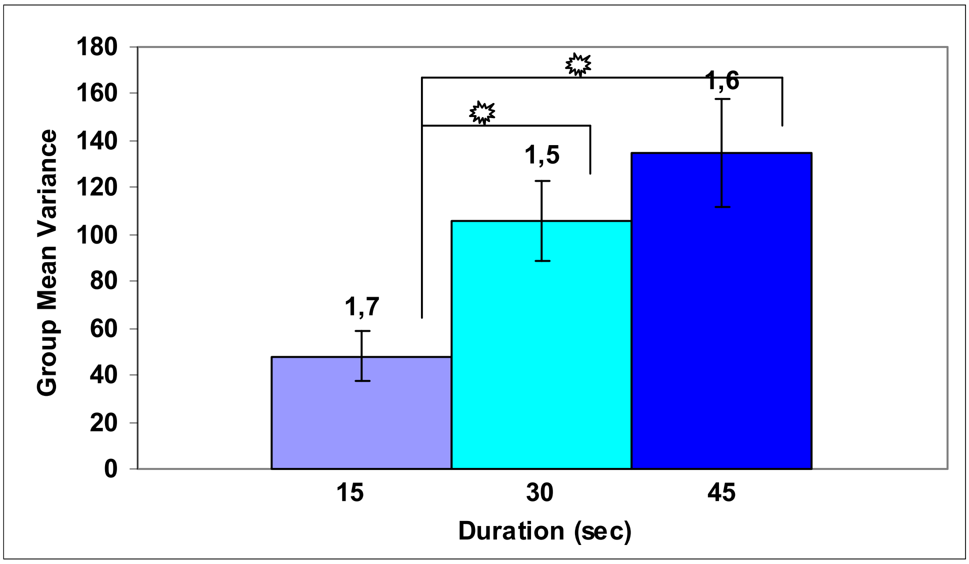

Figure 11. Group Mean Variances and CV (numbers on the bars) for three lengths of duration (Exp-1); error bars indicate SE

Another Repeated measures ANOVA with three levels of duration length was conducted by using coefficients of variation (CV). Coefficient of variations were calculated by dividing variance by mean reproductions. CV is a dependent variable which helps to show the even increase of mean and variance that is expected in time perception studies. It revealed no significant main effect of duration which means that CVs are stable for all duration lengths ($F(2,20) = 0.069$; $p > .05$).

3.1.3. Discussion

The results of Experiment 1 showed that estimations by the duration reproduction method are quite accurate and in parallel with the actual objective durations in the absence of any attention-demanding secondary task. On the other hand, despite the accurate means of duration judgments, reproductions are highly variable which indicates that time perception is highly open to errors and can be called an "estimating" system. Absolute errors of each duration length are an indicator of this higher variability.

The statistical analysis revealed no significant difference between the three durations in their accuracy, but we may claim that there was a tendency for underestimation in the longest duration compared to the other two durations (see Figure 9). Indeed, the binomial (Sign) test revealed this tendency by showing that underestimated trials occurred significantly more frequently than overestimated trials for the longest duration (see Figure 10). Although there was no overall main effect of duration length on the change of variance, we observed an increase in variance with increasing actual duration lengths, as expected. Additionally, this variance increase was significant when comparing the shortest duration with the medium and long duration, as revealed by the Helmert contrast (see Figure 11). Another indicator of variance increase from the shortest to the longest duration was the stable coefficient of variation (CV) across all durations which is confirmed by non-significant effect of duration length on CV. A constant CV is an expected property of the scalar expectancy theory which is confirmed by our results in this first experiment. We furthermore conducted an analysis based on the ratio of the absolute error/variance to see whether there is an additional effect on the accuracy other than the variance increase for longer durations. If there is such another effect on judgements for different duration lengths (e.g., due to boredom), this should become manifest in a significant effect of duration on the absolute error/variance ratio. However, we did not find such an effect and absolute error/variance ratios were the same for all durations.

3.2. EXPERIMENT 2: SECONDARY TEMPORAL TASK

In this experiment, all of the procedures were the same as in Exp-1, except that participants were asked to pay attention to the relative durations of the background colors with respect to each other in addition to the absolute duration of the whole interval. This makes the secondary task a temporal task too. Comparing relative durations of the background colors and indicating them as short, medium and long on a sheet of paper amounts to approximately the same workload (even if workload for both tasks is very small) as in Exp-1. Therefore, the only difference between the two experiments is the necessity to allocate some part of the attentional resources to the secondary temporal task in Exp-2. Any significant difference at reproduced absolute durations can then be attributed to attentional source limitations due to the secondary temporal task. The temporal comparison of the colors by participants was ranked according to accuracy of the sequences.

Specific Hypothesis

The temporal duration judgments in the primary temporal task should be underestimated. Explanation: The secondary temporal task which consumes attentional resources should affect estimated length of the duration in the primary task. This is because participants cannot use their temporal comparisons that are performed in the secondary temporal task by adding them together to reach the entire duration. They had to conclude their duration comparison towards the end of a trial (for the whole duration) and this should leave less attentional resources for the primary task which, in turn, gives rise to an underestimation of the entire duration estimations.

3.2.1. Method:

Participants

A total number of 12 subjects (7 females / 5 males) participated voluntarily in this study. Their mean age was 25.42 years (SD= 2.1). All of them had normal or corrected-to-normal vision.

Procedure

Subjects were informed that they will be asked to judge the relative durations of the background colors before they begin their estimation of the entire interval. They were asked to pay equal attention to both tasks, namely the duration comparison of the three background colors and the time estimation of the entire interval. A black square in the center of the monitor was shown to remind subjects that time is passing. Durations of background colors were randomly changed between the three colors (yellow-red-blue) and white (as the default color). After termination of a trial, they noted the relative length of the colors on a sheet of paper according to their durations on the screen (Appendix B). Subjects indicated the ranking of the background colors' duration by noting long, medium or short into to the blanks according to colors. As an example, they would write "yellow = long, red = moderate, blue = short". The sequence of the background colors was the same for all trials but the colors changed in their durations. During short intervals (15 sec) yellow, red and blue backgrounds were seen on the screen in durations of 1-2 or 3 seconds. The background durations were 2-4-6 sec for moderate and 3-6-9 sec for long intervals. The sequences were scored by the experimenter. If the sequence that subjects noted on the sheet was correct, they would obtain 2 points. On the other hand, if they were correct about the longest duration but they make a mistake about short and moderate colors, they would obtain 1 point. This is because in this example, they distinguished one color's duration as longer than the remaining ones correctly, but they were wrong about what colors had short and moderate length. Therefore they were given half of the total points which is 1 point. As a last option, they could be wrong about the all color durations. For instance, one might say "blue > yellow > red", although the actual sequence was "red > yellow > blue". In this case the subject obtained 0 point since there was no any correct distinguished color duration. Actually, a different scoring strategy in which the highest score was 3 points was also used and we obtained the same results as well.

After writing down the relative durations of background color, participants started and terminated their estimation by pressing a key twice. In that part, there were no changing background colors since this was the duration reproduction part of a trial (Figure 12).

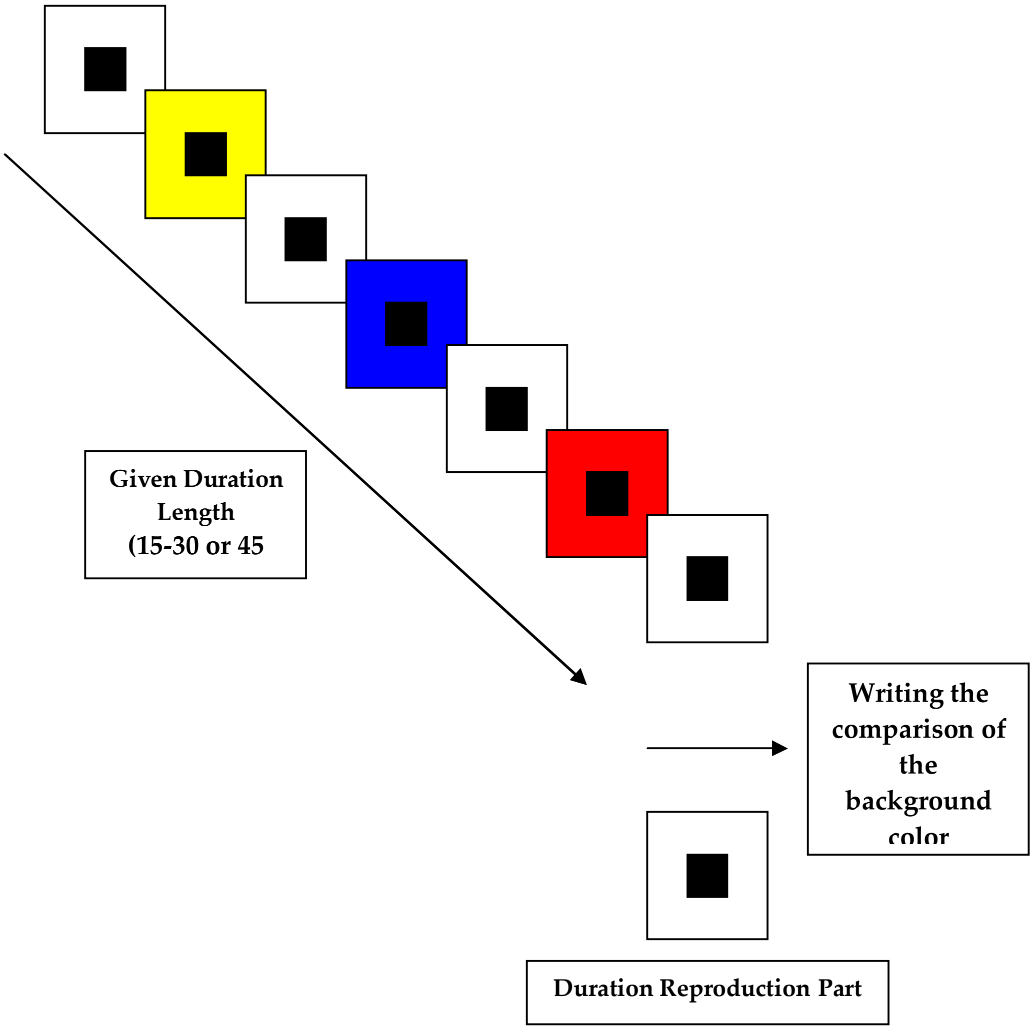

Figure 12. Flow of an experiment trial (Exp-2)

3.2.2. Results

Duration Judgment

A Repeated Measures ANOVA with three duration levels was conducted to reveal whether there is a difference between estimations of different lengths of durations (Table 2). Ratios of participants' reproductions / actual durations were used for the analysis. A significant main effect for duration length was revealed ($F(2, 11) = 10.240$, MSE= 0.012, $\eta_p^2 = .482$ $p < .01$)

Table 2. Estimations for the three levels of duration in the primary time estimation task, together with a secondary temporal task

	Durations		
	15 sec	**30 sec**	**45 sec**
Raw Estimates	13.9 (5.0)	23.8 (7.7)	32.7 (8.2)
Difference Scores	1.1	6.2	12.3
Ratio (Estimates/ActualDuration)	0.93	0.79	0.73
Absolute Errors (sec)	3.3	7.7	12.6
Coefficient of Variation	0.9	1.4	1.1

Tests of within-subject contrasts revealed that moderate durations (M= 23.8, SD= 7.7) were significantly more underestimated than short durations (M= 13.9 SD= 5.0), $F(1,11) = 7.960$, MSE= 0.027, $\eta_p^2 = .420$, $p< .05$), as expected. Furthermore, also long durations (M= 32.7 SD= 8.2) were more underestimated as compared to short duration ($F(1,11) = 13.873$, MSE= 0.012, $\eta_p^2 = .558$, $p < .01$), as expected. The difference between long durations and moderate durations was very close to significance (Figure 13).

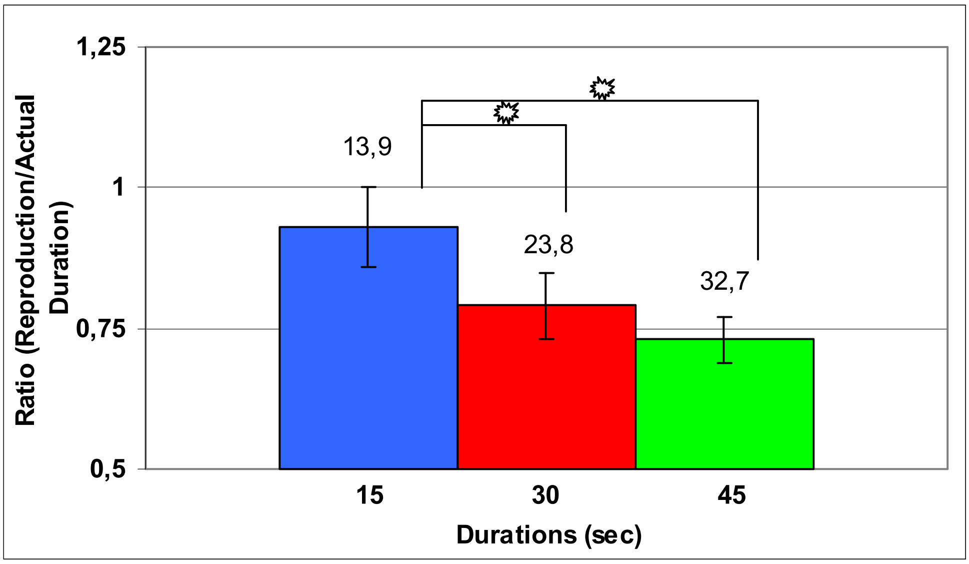

Figure 13. Effect of duration length (Ratio of the estimations and actual duration is shown on y axis, values on the bars are raw estimates for three durations; error bars indicate SE (Exp-2)

A Binomial (Sign) Test based on the difference scores was conducted and revealed that the number of understimated trials for moderate ($Z = 4,71$, $p < .001$) and longest durations ($Z = 6,14$, $p < .01$) was significantly higher than the number of overestimated trials There was no significant difference between number of underestimated and overestimated trials for the short duration ($p > .05$) (Figure 14).

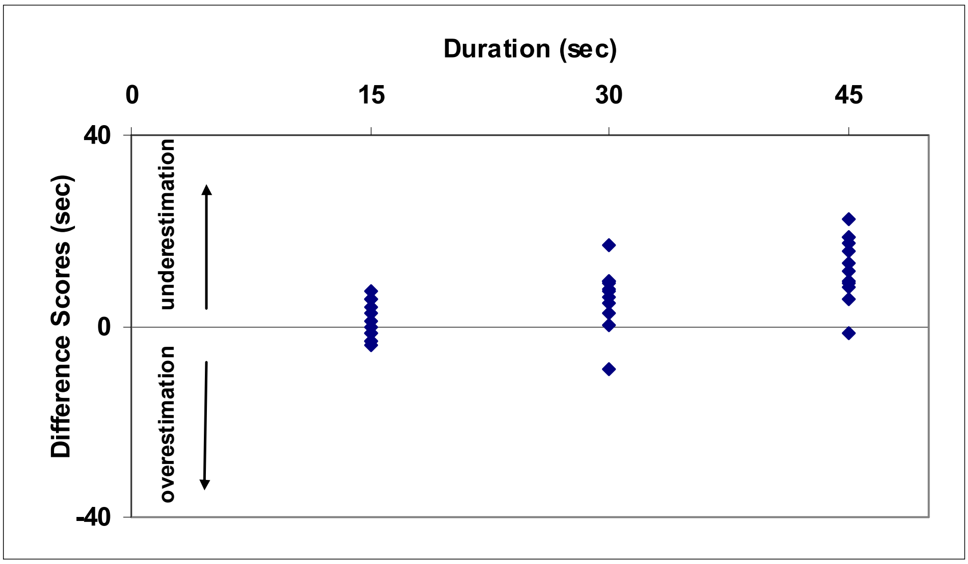

Figure 14. Difference Scores of each subject for the three durations (Exp-2)

Next, a Repeated Measures ANOVA with the three levels of duration was conducted for the Absolute-Errors/Variance ratios. The analysis revealed no significant effect of duration length on these ratios ($F(2,22) = 3.259$, $p > .05$) which suggest that all durations were judged similarly with respect to accuracy.

Also the individual variances were submitted to a Repeated Measures ANOVA. It revealed a significant main effect of duration which implies that the variance in estimations is increasing from shorter to longer durations ($F(2,11) = 4.191$, MSE= 476.2, $\eta_p^2 = .276$, $p < .05$). Moreover, a Helmert contrast revealed a significant variance difference between the first level (short duration) and the remaining durations ($F(1,11) = 27.755$, MSE= 832.7, $\eta_p^2 = .716$, $p < .001$) (see Figure 15 for group mean variances).

Another Repeated measures ANOVA with three levels of duration was conducted for the coefficient of variation (CV) which revealed no significant effect ($F(2,22) = 1.173$, $p > .05$).

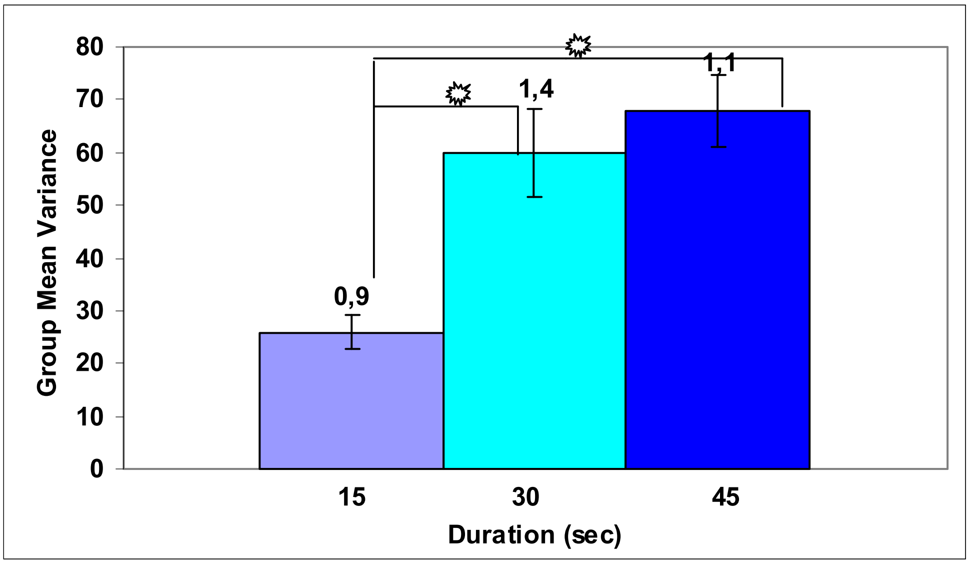

Figure 15. Group Mean Variances and CV (numbers on the bars) for the three levels of duration; error bars indicate SE (Exp-2)

<u>Accuracy of Temporal Comparison</u>

A Friedman Test was conducted to reveal any duration effect on the accuracy of the temporal comparison. It was found that accuracy significantly decreases in parallel with decrease in duration (χ^2 (2) = 6.727, $p < .05$).

Following up on this general result, we furthermore conducted a Wilcoxon Signed Rank Test in order to differentiate significant differences between each duration length. Accuracy was higher for long duration (Mean = 1.85) as compared to moderate (Mean = 1.64) ($Z = -2.687$, $p < .01$) and short duration (Mean = 1.46) ($Z = -2.443$, $p < .0167$), however, there was no significant change between short and moderate durations ($p > .0167$) (Figure 16).

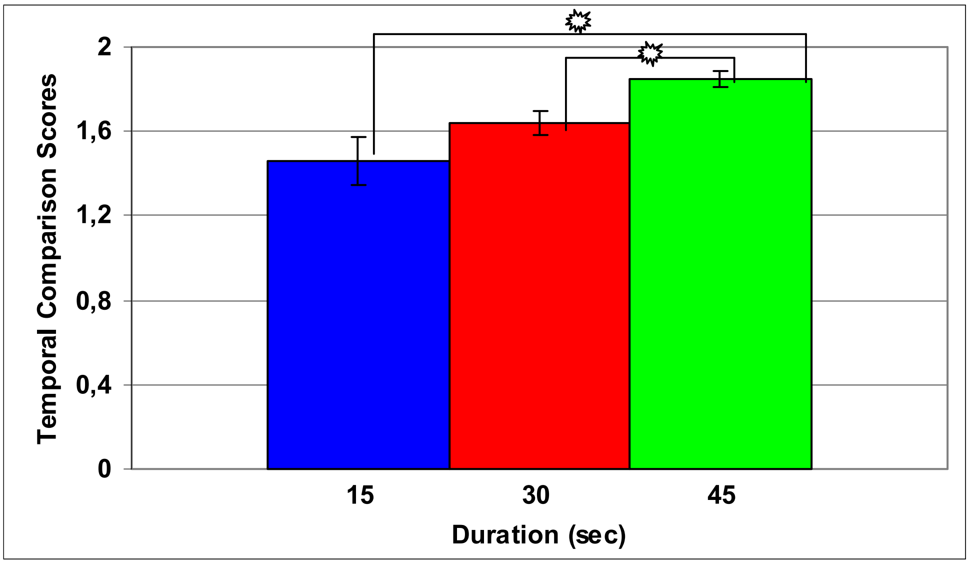

Figure 16. Temporal Comparison Scores; error bars indicate SE (Exp-2)

Comparison of Exp-1 and Exp-2

A mixed ANOVA with the three durations as within-subject factors and Experiment (1,2) as between subjects factors was conducted. We found significant main effect of group (experiment 1-2) on durations which revealed that reproductions in Exp-2 were lower than the reproductions in Exp-1 ($F(1,21) = 5.836$, MSE= 34,5, $\eta_p^2 = .217$, $p < .05$). Additionally, there was a significant interaction between duration and group (experiment) ($F(2,42) = 5.583$, $\eta_p^2 = .21$, $p < .01$). Since we found an interaction, we decided to test further by t-tests to reveal which durations had an effect on this interaction.

Three one-tailed independent samples t-test (Bonferroni corrected) were conducted (by raw reproductions in sec) for the three duration lengths. They revealed a significant group effect for moderate ($t(1,21) = -2.155$, $p < .0167$) and longer durations ($t(1,21) = -2.874$, $p < .01$) indicating that estimations in Exp-2 (secondary temporal task) were lower than the estimations in Exp-1 (empty time) (Figure 17-18). There was no underestimation in Exp-2 compared to Exp-1 for short duration ($F(1,21) = -0.999, p>.0167$)(Figure17&18).

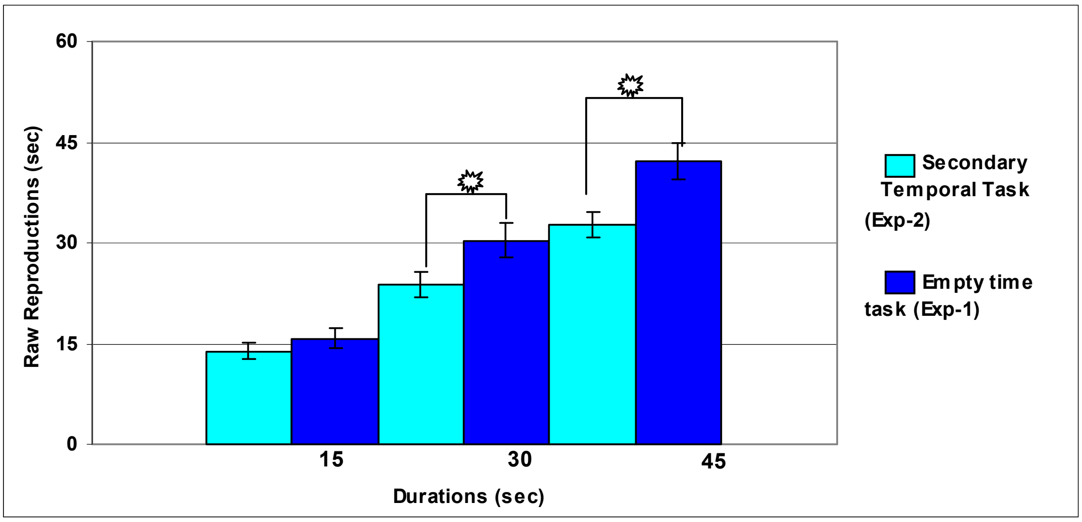

Figure 17. Raw Reproductions in Exp-1 and Exp-2

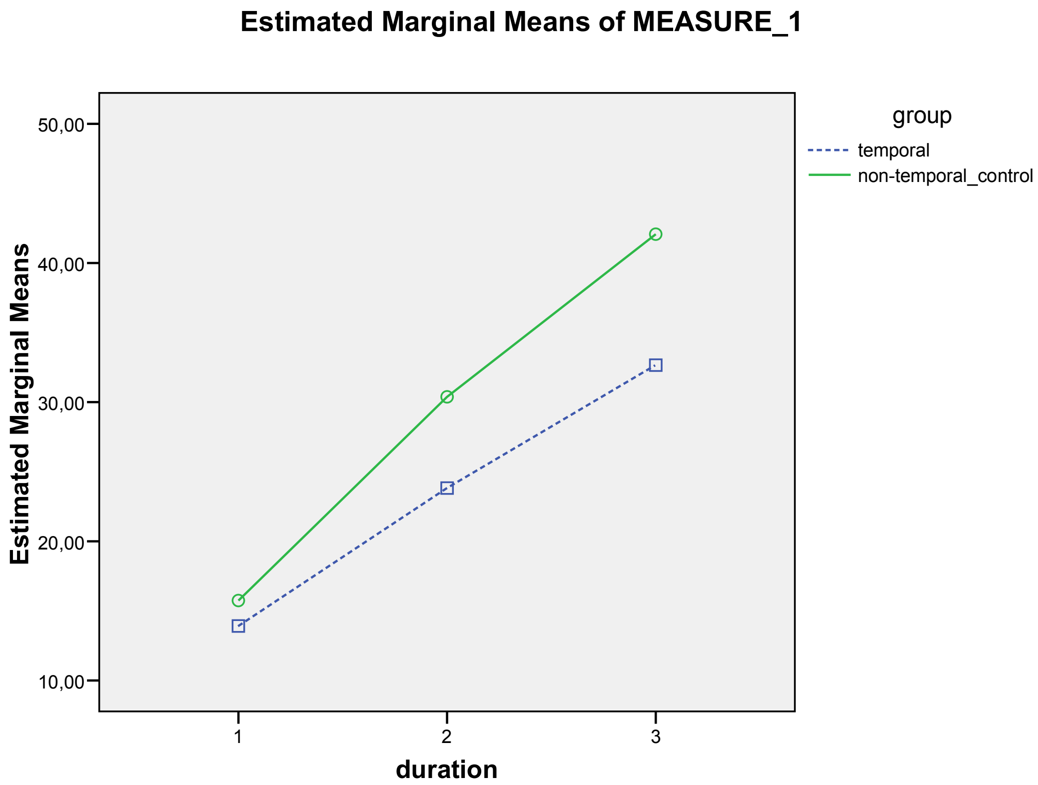

Figure 18. Raw Estimations for Exp-1 and Exp-2 (**1**: short, **2**: moderate, **3**: long)

Moreover, ratio values of all durations in each experiment were combined and a one-tailed independent t-test was conducted which confirmed that overall estimations in Exp-2 (0.82) were significantly lower than the estimations in Exp-1 (ratio= 0.99) $t\ (1,21) = -2.033\ p < .05$ (Figure 19).

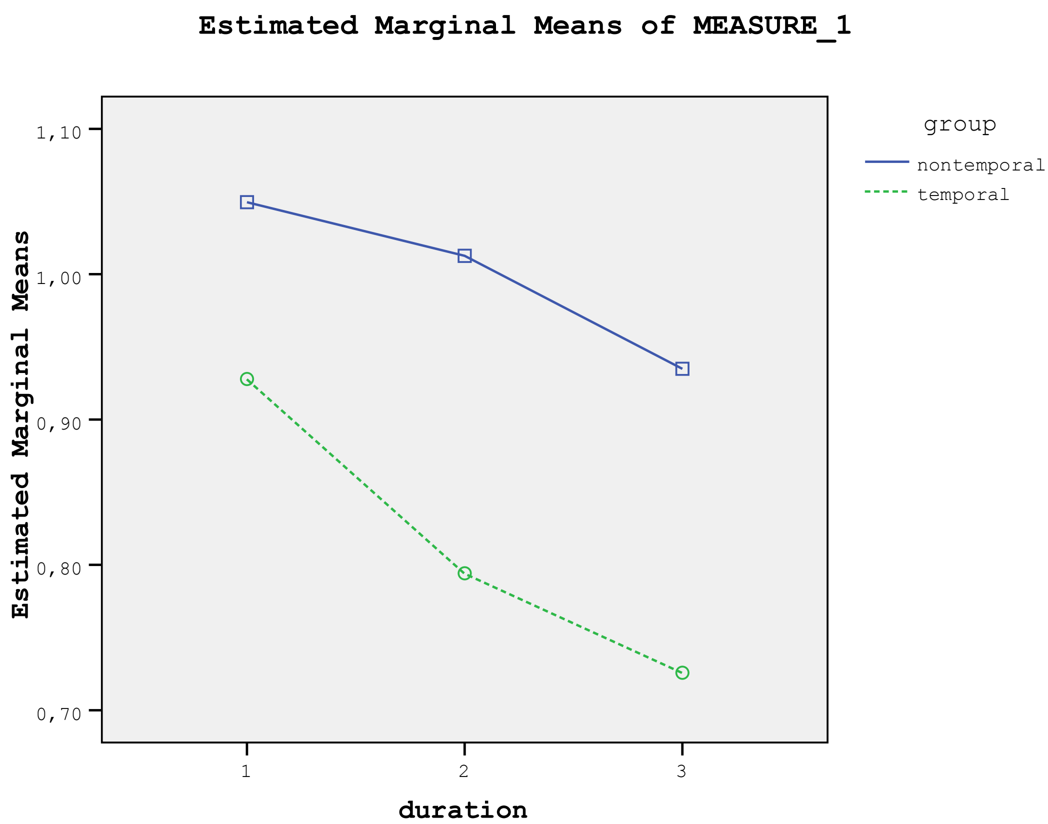

Figure 19. Ratio comparison of durations in Exp-1 and Exp-2 (**1**: short, **2**: moderate, **3**: long)

3.2.3.Discussion

In this experiment, we could observe that underestimation in longer durations are more profound than in shorter durations. There could be various reasons that cause the difference between Experiment-1 and 2 in this respect. Limited attentional resources (which is expected to explain the difference in underestimation between the two experiments) due to the presence of a secondary task (in this case the temporal comparison task in Exp. 2) cannot explain the difference between distinct duration lengths. Note that the relative duration, i.e., the percentage of the secondary task duration (40%) within the entire interval was the same for all durations in

Exp-2. The reason could be that the sustained attentional resource allocation might be more difficult or distracted when there is another task to perform during the interval and longer durations could be affected more profoundly by this distraction. On the other hand, temporal comparison scores of the secondary task also indicate a distinction between the duration lengths which can be the reason for different underestimation levels for different durations. The less underestimated duration is the shortest interval and subjects had significantly lower scores in the temporal comparison task in the shortest duration as well. Therefore, higher levels of attention allocation to the temporal comparison task (secondary task) in longer durations can explain the more profound underestimations in duration reproduction (primary task). But if it is the case, we should still explain the reason why temporal comparison task scores differ in parallel with duration lengths. This question brings us again to the notion of sustained attention allocation for different durations. Although the percentage of the total comparison task duration within the entire interval is constant (40%) for all duration lengths, comparing 1-2 and 3 seconds in the short duration may be performed without sustained attention allocation and may not affect the sources that are used for reproduction of the whole interval. Indeed, working memory supposedly has a temporal expansion of approximately 2 sec. (Baddeley, 1997). If a task keeps within these limits, no additional attention may have to be allocated for processing it. This would explain the relatively less underestimated reproductions in the shorter durations. Low performance of temporal comparison in short durations can already be explained by the relatively small difference (1 second) between durations that are to be compared. In summary, there is no need for the assumption that partcipants had a strategy change between different lengths of durations, i.e., subjects allocate more attentional resources to short primary task intervals and had worse temporal comparison scores. It is more likely that the relatively short durations (1-2-3 sec) that are used in the comparison task of the short entire interval can lead to undistracted sustained attention for the reproduction of the entire interval which, in turn, may have given rise to less underestimation in shorter durations.

The tendency of increasing variance in parallel with increasing duration lengths as observed in Exp-1 turned out statistically significant in Exp-2 as well. Furthermore, CV was stable for all durations in this experiment as well. Again, this might be due to the attentional resource allocation for the secondary task in Exp-2 as compared to control Exp-1. As we expected, overall reproductions in Exp-2 were shorter than reproductions in Exp-1. As stated earlier, the secondary temporal task that is performed within the primary reproduction task may have consumed some part of the limited amount of attentional resources and may have led to the shortened reproductions due to less pulses that are accumulated in short term memory. In addition, we found that the secondary task effect is valid only for moderate and long durations, not for short durations. Despite the 1.8 sec difference in short duration reproduction, it was not statistically significant, at least for the number of trials and subjects that we used in these experiments. It was already expected to find more accurate reproductions in shorter durations due to the fact that they are more managable considering the highly variable time perception phenomenon.

3.3. EXPERIMENT 3: SECONDARY NON-EXECUTIVE TASK

This experiment is thought to be the control of Exp-4 and requires less amount of non-temporal processing compared to Exp-4. The task does not include any conflict resolution and serves simply to fill the empty time of the experimental session. However, non-temporal processing was required in the form of continuous button presses during the experiment. The only difference between Exp-3 and 4 was the executive task incorparated in Exp-4.

Hypotheses

We generally expected underestimations for the multi-seconds reproduced durations as compared to objective durations for all experiments. The absence of conflict resolution in this experiment should give rise to lengthened reproductions compared to Exp-4 due to more attention resource allocation to the temporal processor. On the other hand, mean reproductions should be shortened as compared to Exp-1 (empty time) since there is still an attention-demanding task as opposed to Exp-1.

3.3.1. Method:

Participants

11 Subjects (5 females / 6 males) with mean age of 25.5 years (SD= 3.5) participated voluntarily in this study. All of them had normal or corrected-to-normal vision.

Procedure

Subjects had to perform a non-executive, non-temporal task within three different intervals. In the task, a red rectangle was seen either on the left or on the right randomly. Participants were asked to press the left or right button according to what they saw on the screen. They used both hands during the experiment. The task design was simple, however, replicated the executive task (that is involved in Exp-4) in its perceptual workload and motor action characteristics, except the workload due to interference as is characteristic of the secondary task of Exp-4. A black square was in the center of the screen all the time during the task as in the previous experiments. After completion of a given duration, an instruction page was shown to inform the subjects to continue with the duration reproduction part of the trial. This instruction page was useful in that it allowed subjects to start their reproduction of the duration themselves. The interval reproduction part could be started immediately after a given duration since participants learned what was written on the instruction page in the practice phase and passed quickly over to the experimental session. After the instruction page, the same black square was seen on the screen as in the other experiments to let them know the clock was ticking. Then they had to press a defined button to stop their estimation for the most recent duration that they performed the secondary task (Figure 20).

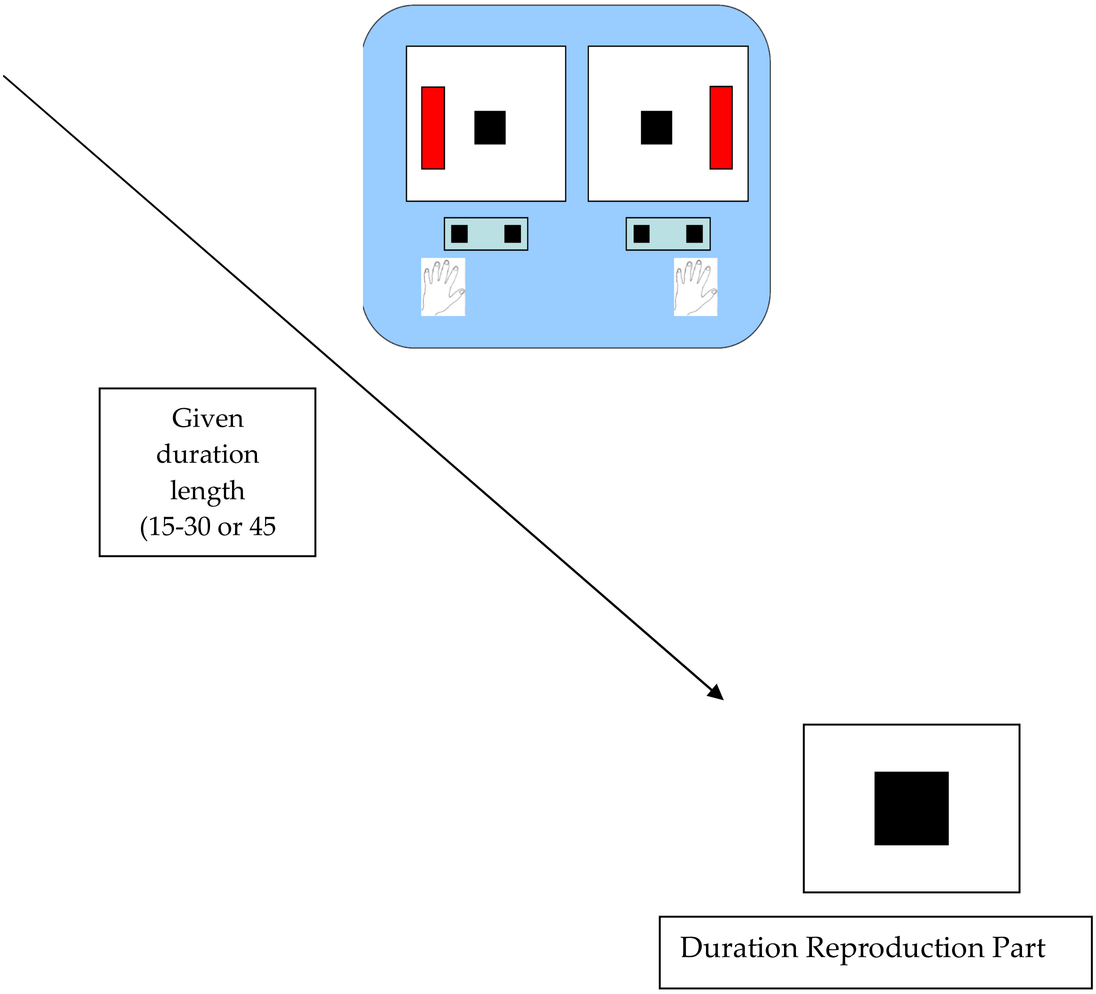

Figure 20. Flow of an experimental trial (Exp-3)

3.3.2. Results

Duration Judgments

A repeated measures ANOVA with three duration levels was conducted to reveal whether there was a difference between estimations of different lengths of durations (Table 3).

Table 3. Reproductions for three levels of duration in the reproduction task with a secondary non-executive task

	Durations		
	15 sec	**30 sec**	**45 sec**
Raw Estimates (SD)	14.1 (3.4)	26.3 (7.7)	36.1 (9.1)
Difference Scores (sec)	0.9	3.7	8.9
Ratio (Estimates/ActualDuration)	0.94	0.88	0.80
Absolute Errors (sec)	3.7	8.9	12.7
Coefficient of Variation	0.9	1.8	2.2

Ratios of participants' reproduction and actual durations were used for the analysis which revealed marginal main effect for duration length ($F(2,20)= 3.440$, MSE= 0.016, $\eta_p^2 = .256$, $p = .052$) (Figure 21).

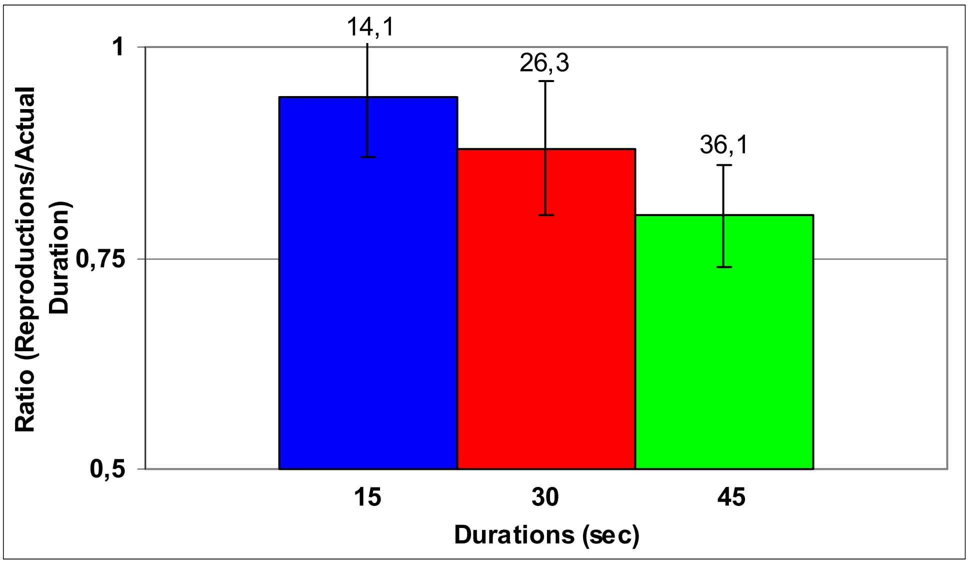

Figure 21. Effect of duration length (Ratio of the reproductions over actual durations is shown on the y axis, values on the bars are raw reproductions for the three durations; error bars indicate SE (Exp-3)

A Binomial (Sign) Test showed that the number of understimated trials was significantly higher than the overestimated trials in moderate (30 sec) ($Z = 2.35$, $p < .05$) and long (45 sec) durations ($Z = 3.88$, $p < .01$). Participants performed approximately the same number of underestimated and overestimated trials in the short duration (15 sec) ($Z = 1.49$, $p > .05$) (Figure 22).

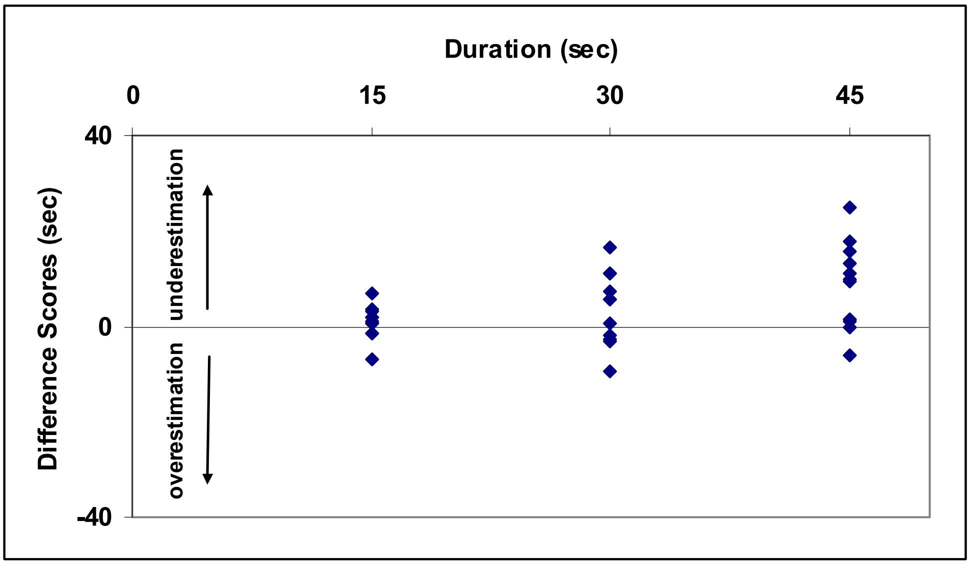

Figure 22. Difference Scores of each subject for duration lengths (Exp-3)

Furthermore, Absolute-Errors/Variance were used to conduct Repeated Measures ANOVA with three levels of duration which revealed no significant effect of duration length on absolute errors ($F(2,20)= 0.071$, $p > .05$).

A Repeated Measures ANOVA with individual variances revealed a significant main effect of duration indicating that variance of estimations is increasing from shorter to longer duration ($F(2,10) = 11.684$, $MSE= 1137$, $\eta_p^2 = .539$ $p < .01$). Moreover, Helmert contrasts revealed a significant variance difference between the first level (short duration) and the remaining durations ($F(1,10) = 14.713$, $MSE= 2208$, $\eta_p^2 = .595$, $p < .01$) and between the moderate duration and the long duration ($F(1,10) = 6.121$, $MSE= 1603$, $\eta_p^2 = .380$, $p < .05$) (see Figure 23 for group mean variances)

Another Repeated measures ANOVA with three levels of duration length was conducted by using coefficient of variations (CV). It revealed a significant effect of duration as ($F(2,10) = 7.226$, $MSE= 0.705$ $\eta_p^2 = .419$, $p < .01$), opposed to previous experiments .

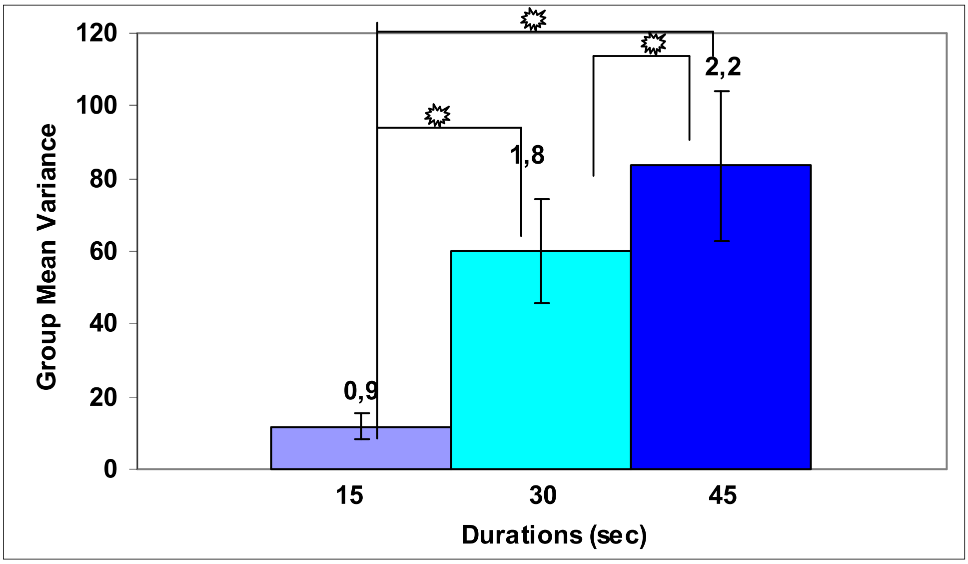

Figure 23. Group Mean Variances and CV (numbers on the bars) for the three levels of duration; error bars indicate SE (Exp-3)

<u>Comparison of Exp-1 and Exp-3</u>

A mixed ANOVA with the three durations as within-subject factors and Experiment (1,3) as between subjects factors was conducted. We found no significant main effect of group (experiment 1-3) on durations ($F(1,20) = 2.092$, $p > .05$). Since we found no interaction between duration and group(experiment) we did not further test the durations with t test. Analysis showed no significant effect of group on duration lengths despite the tendency that reproductions in Exp-3 were shorter than in Exp-1, especially for longer duration level (Figure 24).

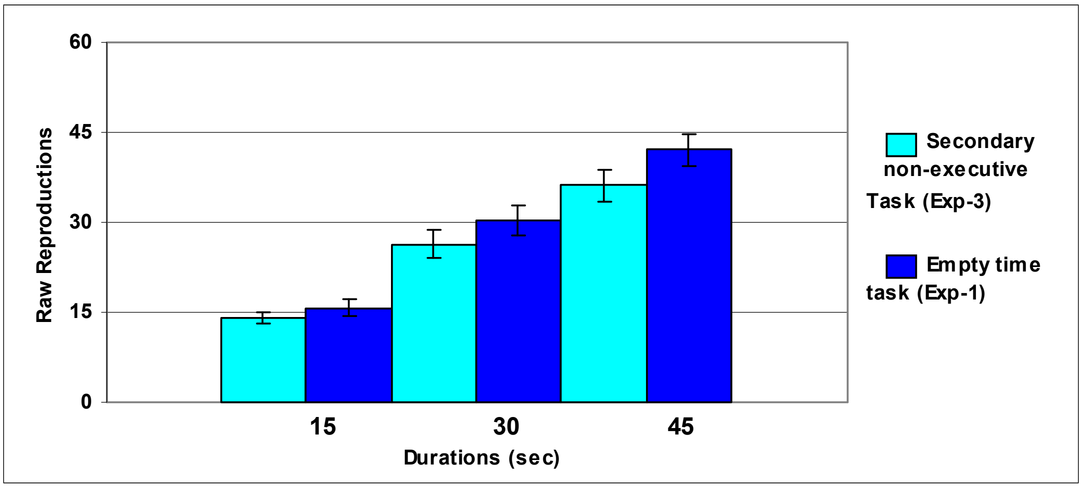

Figure 24. Raw Reproductions in Exp-1 and Exp-3

3.3.3.Discussion

This experiment was designed as the control experiment for Exp-4 which tested the effect of executive processing on duration judgements. Therefore, this research question will be discussed after introducing the last experiment in the next secton.

Nonetheless, we can still discuss within-subject results of Exp-3 and compare them with Exp-1 (which is the control case for all experiments).

A statistically marginal decline of the reproduced/actual duration ratio with increasing actual (objective) interval lengths was observed (see Figure 21). We observed a significant duration length effect on reproductions only in Exp-2 (secondary temporal task) among the three experiments including this one. There was a strong tendency for this effect in Exp-3 and a weaker tendency in Exp-1. The results based on these three experiments may be a sign of a hierarchical effect of the workload and attention demanding tasks on duration judgements. Exp-1 had no secondary task and showed a weaker tendency of underestimation in longer durations. Exp-3 revealed a strong tendency, but not significant, for the duration length effect on underestimation rates. This could be explained by the presence of a regular secondary task (pressing right or left buttons in response to right or left rectangles, respectively) which brings some but not too much workload with it and demands some attention of the non-temporal processor. As compared to the empty time duration judgements performed in Exp-1, there should be less attentional resources for the temporal processor in Exp-3. This would explain the higher degree of underestimation for the longer durations in Exp-3, which may have been affected more profoundly by that limited attentional resource. In Exp-2 (secondary temporal task) decreasing reproduced/actual duration ratiso with increasing interval length is a significant affect with a medium effect size. Allocating attentional resources to the secondary temporal task in Exp-2 caused limitations for the primary duration judgements. In turn, this gave rise to more profound and statistically significant effects on longer durations in Exp-2. The Binomial (Sign) test was also an indicator of a higher number of underestimated individual trials for longer durations in the previous experiments containing attention demanding tasks. In Exp-1, only the longest duration had significantly more underestimated trials. But it turns out that moderate durations as well had significantly more underestimated trials compared to overestimated ones in Exp-2 and Exp-3 (attention demanding tasks).

Parallel variance increments with duration length increases was also confirmed in this experiment. But interestingly, the coefficient of variation (CV) was not stable for all durations as opposed to the previous experiments. As it is seen in Figure 23, very diminished variance in short duration condition might be the reason of the significant difference in overall CV comparison (CV is calculated by variance/mean). Somehow, participants judged the short durations less variably.

Although we did not hypothesize any between-subject effects for Exp-1 and Exp-3, we conducted statistical analysis to see if there were any. There was marginally significant effect of group (experiment) on duration judgments indicating the difference in reproduced durations (especially for moderate and longest intervals) between the two experiments (see Figure 24). Probably, the presence of the workload in Exp-3 gave rise to underestimation to some extent as compared to the empty temporal task (in Exp-1), however, it was not profound as in Exp-2 and Exp-4 (as you see within the next parts of this chapter). Moreover, we can already accept the results (comparison of Exp-1-3) as significant since we have a directed hypothesis stating non-temporal non-executive task (Exp-3) should give rise to underestimation as well.

3.4. EXPERIMENT 4: SECONDARY EXECUTIVE TASK

This experiment was conducted in order to reveal the effect of a secondary executive task on reproduced durations. A Simon task is used for this purpose. Automatic processing of spatial stimuli and correct reponse selection requirements lead to the S-R compatibility effects giving rise to a conflict to be resolved. More detailed information about the nature of the Simon task was given in Chapter 2 and you will find the specifics of the task in the subsequent section. As all interference tasks, the Simon task is expected to consume a relatively high amount of the attentional resources. Indeed, resolving the conflict between task-irrelevant spatial information of the stimulus and the response code causes subjects' attention to shift to the non-temporal processor. Simon task data was also obtained to see whether there is an effect of the duration judgement task on the Simon effect itself and possibly on its effect function. The Simon task data in this experiment will be compared with our previous study (Duzcu & Hohenberger, 2009) in which only the Simon task was conducted.

Hypotheses

We expect to observe the shortest reproductions in this experiment within all of the experiments. Moreover, durations should in particular be underestimated as compared to Exp-3 if there is a stronger effect of performing an executive task on temporal duration judgements than a non-temporal task that lacks conflict resolution.

3.4.1. Method:

Participants

A total number of 13 subjects (6 females / 7 males) participated voluntarily in this study. Their mean age was 26.09 years (SD= 2.3). All of them had normal or corrected-to-normal vision. Two participants were excluded from the analysis because after the experiment they stated that they counted when they were given the duration to reproduce.

Procedure

Durations used in the practice (12-25-37 sec) and experimental session (15-30-45 sec) were the same as in the previous experiments. Color was the non-spatial task-relevant dimension. Rectangles in two different colors (blue and red) were presented in left or right positions. The mapping rules between color and key were "red-left/blue-right" for the task. Subjects were instructed to ignore the location of the stimulus, i.e., spatial location was task-irrelevant. Subjects were instructed to react to the stimuli in accordance with the pre-specified rule as quickly and as accurately as possible and to pay attention to the temporal duration while they perform the task. After they performed the task for a randomly given duration, a black square in the middle of the screen appeared alerting them of their subsequent reproduction estimation. Participants let time pass according to their temporal judgement and then pressed a button to stop their estimation for that trial. Then they continued with the next trial which had the same structure. The flow of the experimental session is visualized in Figure 25. There were again 5 trials for each length of durations, that is, 15 trials in total.

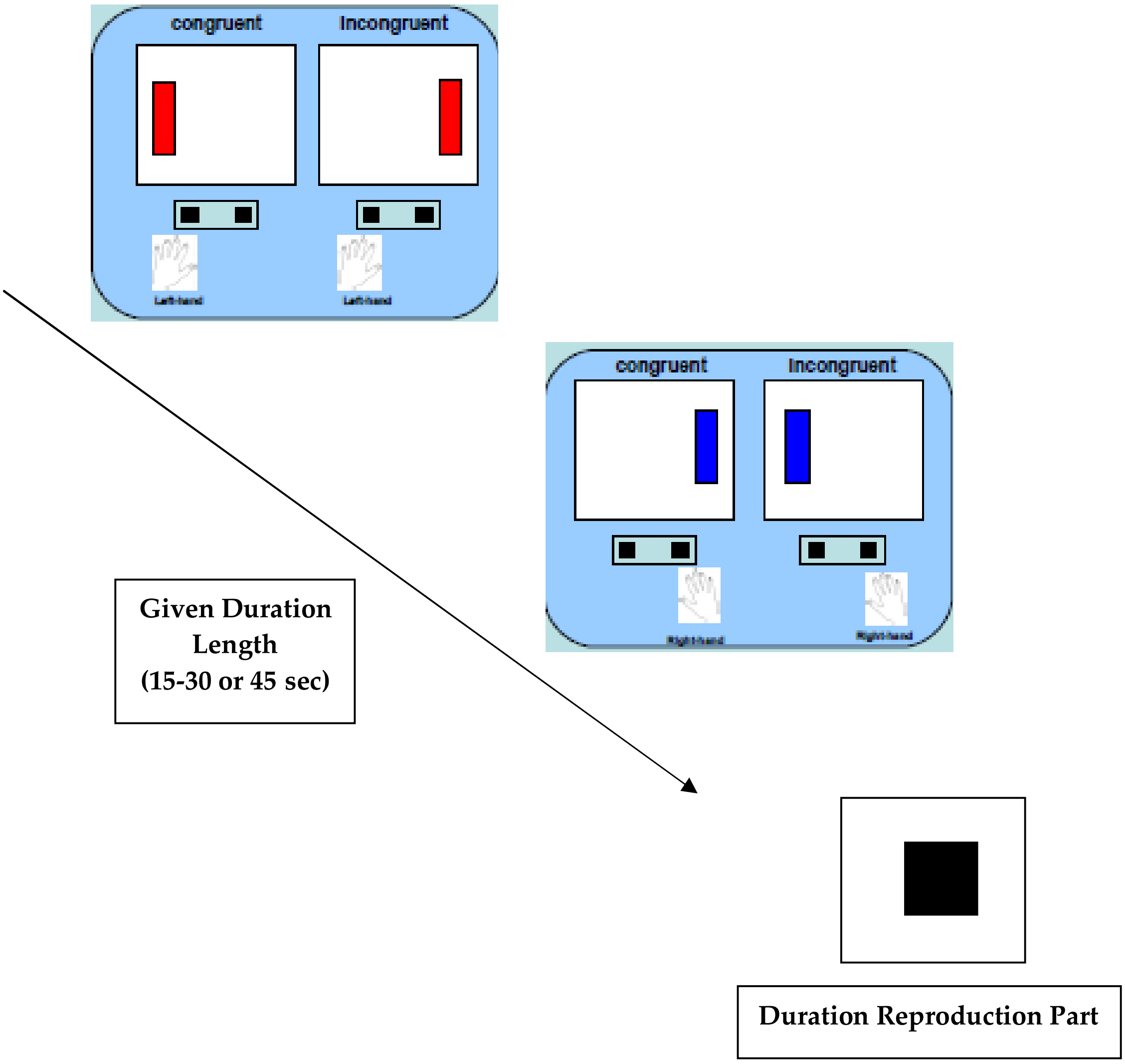

Figure 25. Flow of an experiment trial (Exp-4)

3.4.2. Results

<u>Duration Judgements:</u>

A Repeated measures ANOVA with three duration levels was conducted in order to find out whether there is a difference between reproductions of different lengths of durations (Table 4). Ratio of the participants' estimations and actual durations were used for the analysis which revealed a significant main effect for the duration length ($F(2, 10) = 57.192$, $MSE = 0.004$, $\eta_p^2 = .851$, $p < .001$).

Table 4. Estimations for three levels of duration in time reproduction task with a secondary executive task

	Durations		
	15 sec	**30 sec**	**45 sec**
Raw Estimates (SD)	12.6 (4.5)	19.6 (6.8)	25.1 (8.6)
Difference Scores	2.4	10.4	19.9
Ratio (Estimates/ActualDuration)	0.84	0.65	0.56
Absolute Errors (sec)	2.7	10.4	19.9
Coefficient of Variation (Variance/Mean)	1.1	1.2	1.6

Tests of within-subject contrasts revealed that moderate (M= 19.6, SD= 6.8) durations were significantly more underestimated than short durations (M= 12.6, SD= 4.5) ($F(1,10) = 79.001$, $MSE = 0.005$, $\eta_2 = .888$,$p < .001$). Moreover, long durations (M= 25.1, SD= 8.6) were also more underestimated than moderate durations ($F(1, 10) = 17.872$, $MSE = 0.006$, $\eta_p^2 = .641$, $p < .01$).

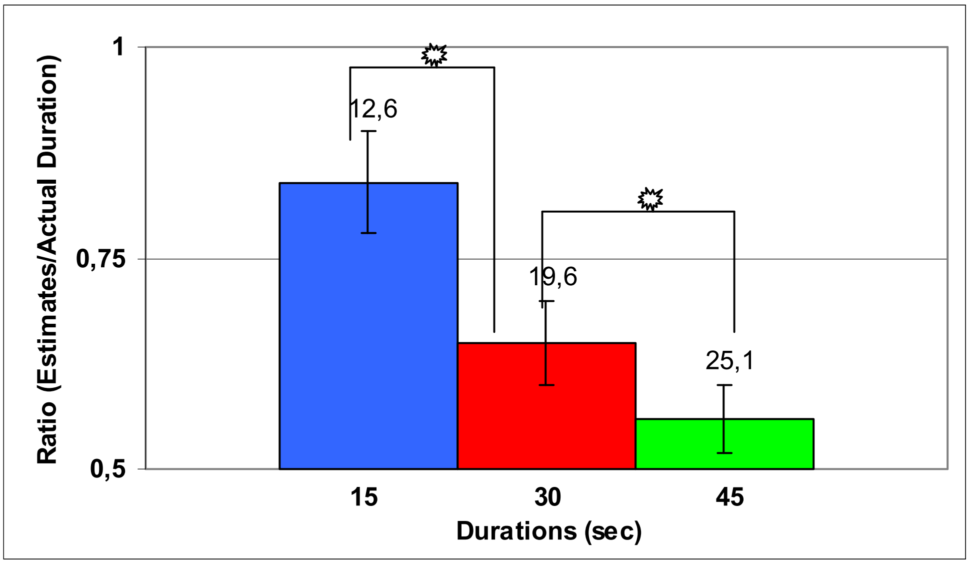

Figure 26. Effect of duration length (Ratio of estimations and actual durations is shown on the y axis, values on the bars raw estimates for the three durations are shown; error bars indicate SE (Exp-4)

A Binomial (Sign) Test was significant for all durations (short: Z = 2.94, p < .01; moderate: Z = 5.82, p< .00; long: Z = 7.35, p < .00) which means that the number of understimated trials was higher than the number of overestimated trials (Figure 27).

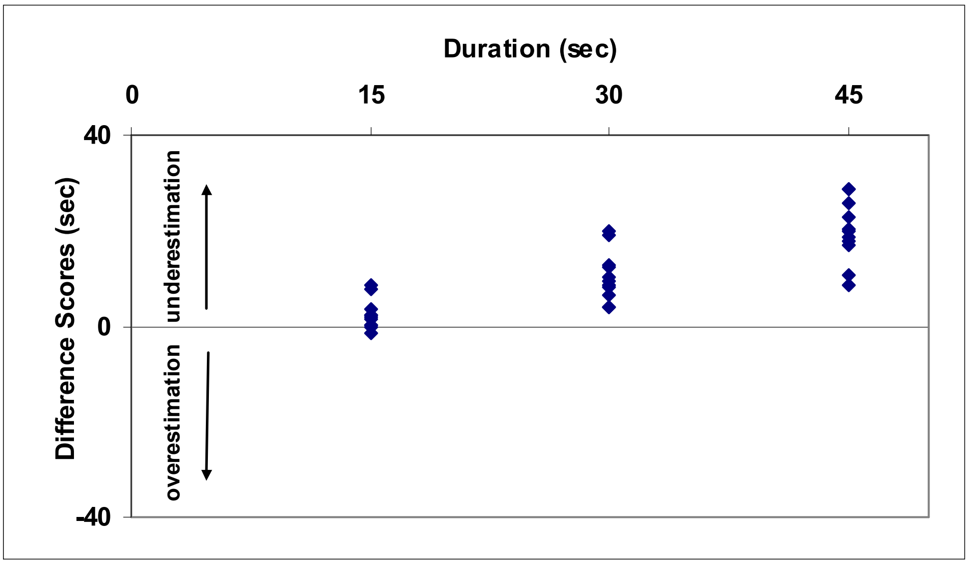

Figure 27. Difference Scores of each subject for durations lengths (Exp-4)

Absolute-Errors/Variance were used to conduct another repeated measures ANOVA with three levels of duration. It revealed a significant effect of duration length on absolute errors ($F(2,10) = 6.023$, MSE= 0,002, $\eta_p^2 = .376$, $p < .01$) indicating an increase in absolute errors in parallel with duration length increase.

A Repeated Measures ANOVA with individual variances revealed a significant main effect of duration indicating that variance of estimations is increasing from shorter to longer durations ($F(2,10) = 5.051$, MSE= 488, $\eta_p^2 = .336$, $p < .05$). Moreover, Helmert contrasts revealed a significant variance difference between the first level (short duration) and the remaining levels ($F(1,10) = 6.679$, MSE= 650, $\eta_p^2 = .400$ $p < .05$) (see Figure 28 for group mean variances) and between moderate and long durations (one tailed-directed hypothesis) ($F(1,10)= 3.752$, MSE= 1087, $\eta_p^2 = .273$, $p < .05$).

Another Repeated measures ANOVA with three levels of duration length was conducted by using coefficients of variance (CV) which revealed no significant effect of duration ($F(2,20) = 1.480$, $p > .05$, $\eta_p^2 = .129$).

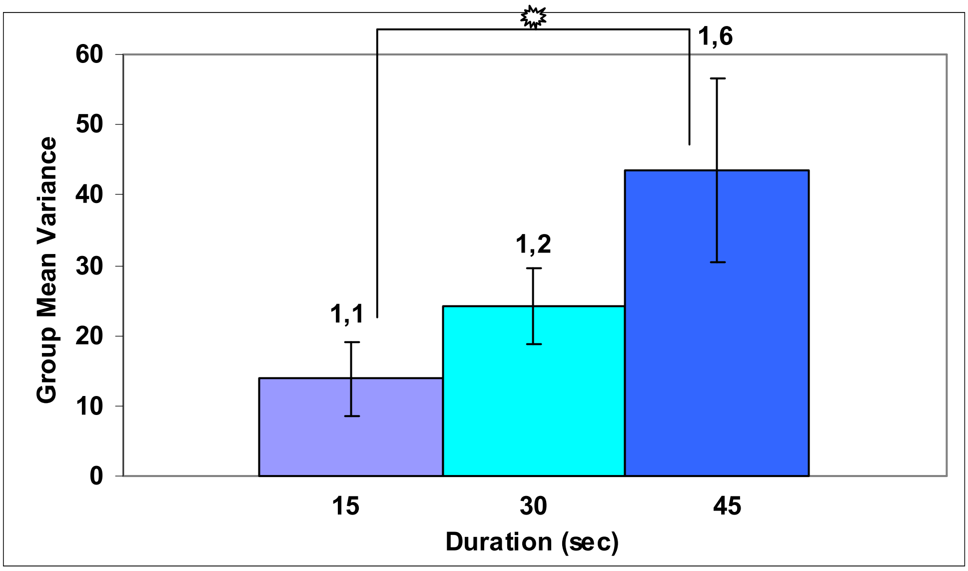

Figure 28. Group Mean Variances (on the y axis) and CVs (on top of the bars) for the three levels of duration; error bars indicate SE (Exp-4)

Simon Task

Outliers (RTs > 2 SD's) were removed from the raw data and subsequent analyses were based on this adjusted data. A 2 (+/- congruency) x 9 (bins) repeated measures ANOVA was conducted. We divided the Simon task data into 9 bins to be able to obtain an effect function. Each bin had ≈ 11% of the data in which RTs were arranged from faster (lower RT) to slower (higher RT) responses (see Duzcu & Hohenberger, 2009). Therefore we could obtain an effect function by placing Simon effect sizes for each bin at y axis and the bins at the x axis.

There was a main effect of "congruency" ($F(1, 10) = 37.522$, $MSE = 470$, $\eta_p^2 = .790$ $p < .001$) which indicates that participants showed faster reactions to congruent trials (M=547.1 ms, SE=26.48) than to incongruent ones (M=565.9 ms, SE=27.88). The mean difference between congruent and incongruent trials, i.e., the Simon effect, was 18.8 ms. There was an interaction between bins and congruency ($F(1, 8) = 3.302$, MSE= 45,587, $\eta_p^2 = .248$, $p < .01$) meaning that effect sizes were different throughout the bins which is already an expected result supported by our previous study.

We also compared the Simon task data of Exp-4 with a previous study in which the same task was conducted alone to see whether there is an effect of the time estimation task on the Simon task. A 3-factorial mixed ANOVA with 2 (+/- congruency) x 2 (experiments: Simon only vs. Simon task during time estimation task) x 9 (bins) design was conducted. We did not find a significant effect of experiment ($p > .05$), which indicates that there is no effect of the time estimation task on the Simon task. There was no significant three-way interaction between congruency, bins and experiment implying statistically similar effect functions for both data sets across bins ($p > .05$) (Figure 29). Although there was a smaller Simon effect in the Simon task during time estimation as compared to the Simon task only, it was not significant. Although the absence of a three-way interaction implies similar effect functions for both data sets, there was a shift in the effect function of the horizontal Simon task in Exp-4 (Figure 29).

Estimated Marginal Means of MEASURE_1

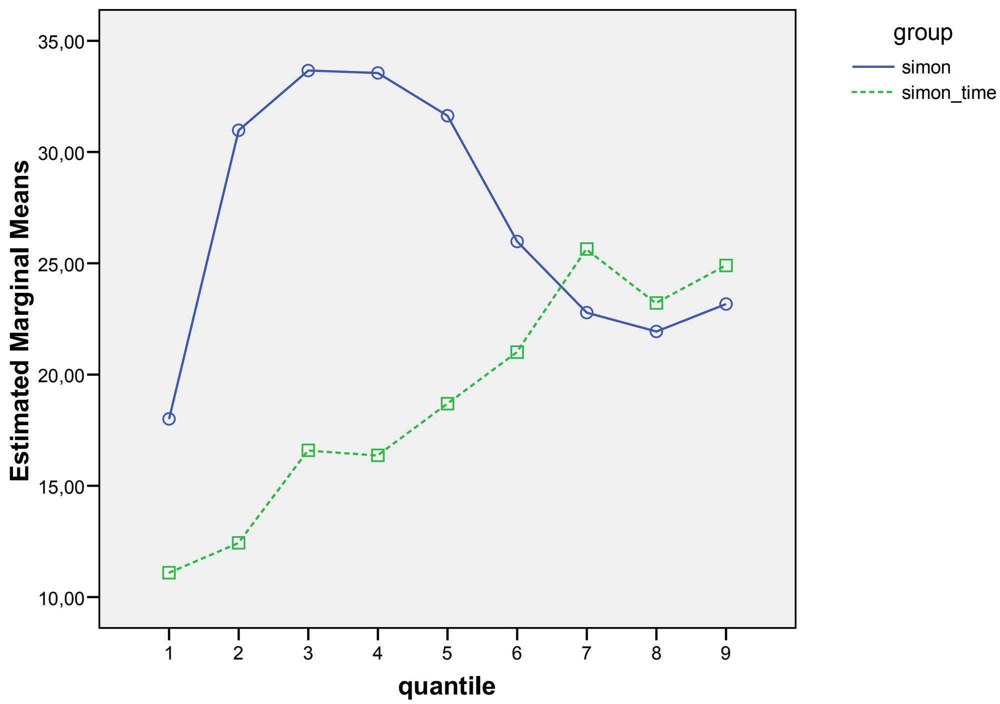

Figure 29. Effect Function of Simon task only (previous study) and Simon Task in Exp-4

<u>Comparison of Exp-1 and Exp-4</u>

A mixed ANOVA with the three durations as within-subject factors and Experiment (1,4) as between subjects factors was conducted. We found significant main effect of group (experiment 1-4) on durations which revealed that reproductions in Exp-4 were lower than the reproductions in Exp-1 ($F(1,20) = 17.690$, MSE= 32,879, $\eta_p^2 = .469$, $p < .00$). Additionally, there was a significant interaction between duration and group (experiment) ($F(2,40) = 19.525$, $\eta_p^2 = .494$, $p < .00$) (Figure 30). Since we found an interaction, we decided to test further by t tests to reveal which durations had an effect on this interaction.

Estimated Marginal Means of MEASURE_1

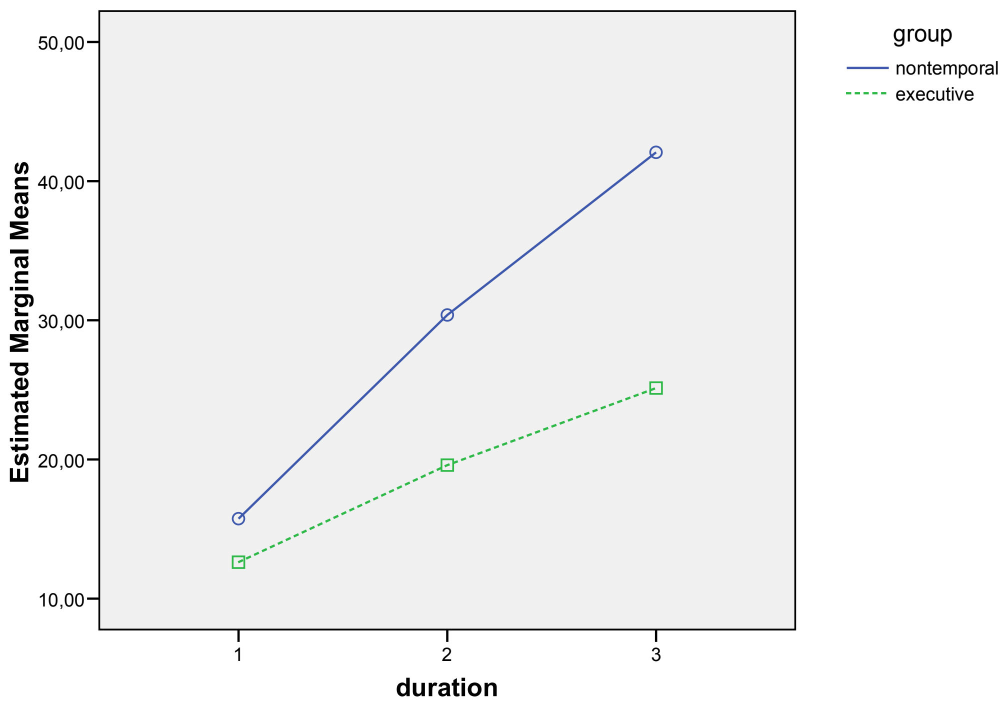

Figure 30. Raw Estimations for Exp-1 and Exp-4 (**1**: short, **2**: moderate, **3**: long)

Three independent samples t-tests (one-tailed for the short duration) were conducted (by raw reproductions in sec) for the three duration lengths. They revealed a significant group effect for moderate (t (1,20) = 3.654, p < .01) and longer durations (t(1,20) = 5.103, p < .00), but not for short (t (1,20) = 1.774, p > .05) indicating that estimations in Exp-4 (secondary executive task) were lower than estimations in Exp-1 (empty time) (Figure 31).

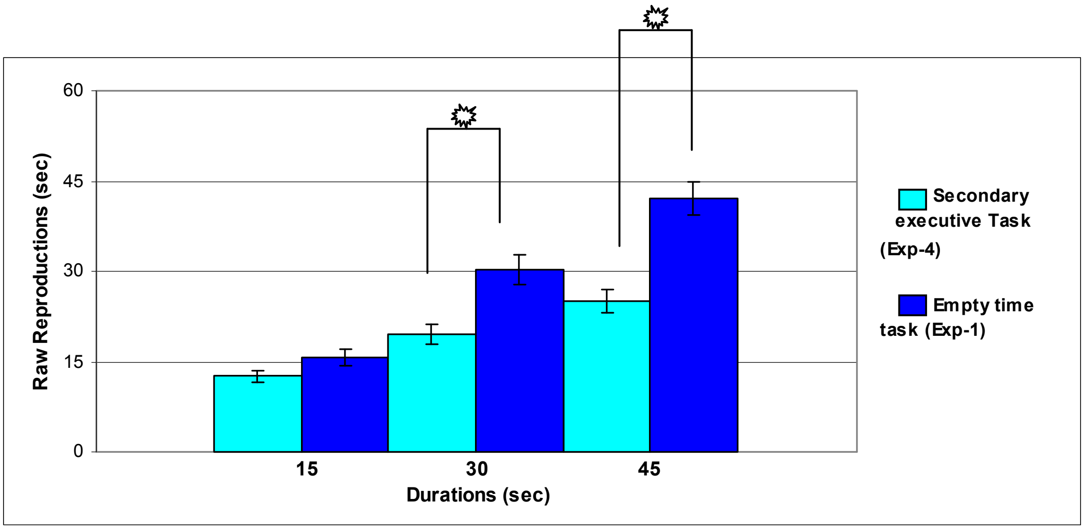

Figure 31. Raw Reproductions in Exp-1 and Exp-4

Moreover, ratio values of all durations in each experiment were combined and an independent samples t-test was conducted which confirmed that overall estimations in Exp-4 (0.68) were significantly lower than estimations in Exp-1 (ratio= 0.99) (t (1,20) = 3.545 p < .01).

<u>Comparison of Exp-2 and Exp-4</u>

A mixed ANOVA with the three durations as within-subject factors and Experiment (2,4) as between subjects factors was conducted. The result was a marginally significant main effect of group (experiment 2-4) on durations indicating that reproductions in Exp-4 were lower than the reproductions in Exp-2 (F(1,20) = 4.283 , MSE= 25,382, η_p^2 = .169 , p = .051). Moreover, ratio values of all durations in each experiment were combined and a one -tailed independent samples t-test was conducted which confirmed that overall estimations in Exp-4 (0.68) were significantly lower than estimations in Exp-2 (ratio= 0.82) (t (1,21) = 1.742, p < .05).

Additionally, there was a significant interaction between duration and group (experiment) in Mixed Anova ($F(2,40) = 7.986$, $\eta_p^2 = .276$, $p < .01$) (Figure 32). Since we found an interaction, we decided to test further by t tests to reveal which durations had an effect on this interaction.

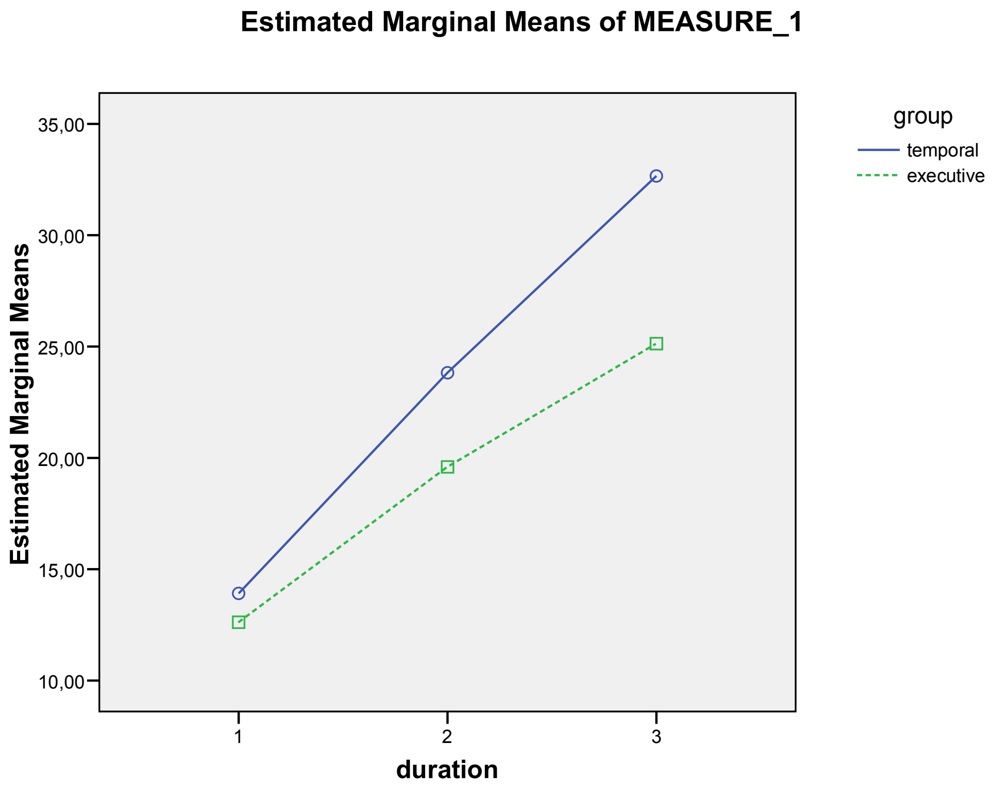

Figure 32. Raw Estimations for Exp-2 and Exp-4 (**1**: short, **2**: moderate, **3**: long)

Three independent samples t-tests were conducted (for raw reproductions in sec) for the three duration lengths. They revealed a significant group effect for longer durations ($t(1,21) = 2.749$, $p < .0167$), indicating that reproductions of long durations in Exp-4 (secondary executive task) were lower than reproductions in Exp-2 (secondary temporal). There was no difference in underestimation in Exp-4 compared to Exp-2 for short and moderate durations ($p > .0167$) (Figure 33).

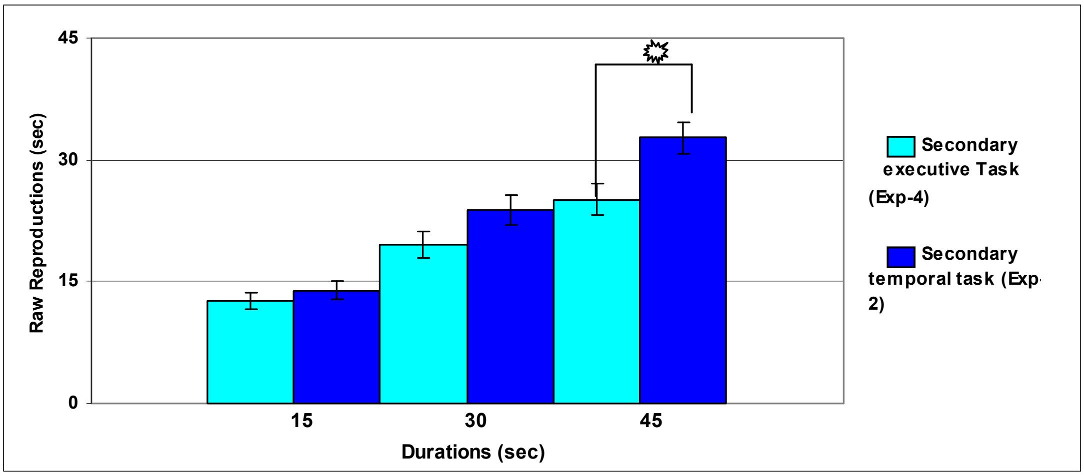

Figure 33. Raw Reproductions in Exp-2 and Exp-4

Comparison of Exp-3 and Exp-4

A mixed ANOVA with the three durations as within-subject factors and Experiment (3,4) as between subjects factors was conducted. We found significant main effect of group (experiment 3-4) on durations which revealed that reproductions in Exp-4 were lower than the reproductions in Exp-3 ($F(1,20) = 7.313$, MSE= 30,543, $\eta_p^2 = .268$, $p < .05$). Additionally, there was a significant interaction between duration and group (experiment) ($F(2,40) = 9.485$, $\eta_p^2 = .322$, $p < .00$) (Figure 34). Since we found an interaction, we decided to test further by t tests to reveal which durations had an effect on this interaction.

Estimated Marginal Means of MEASURE_1

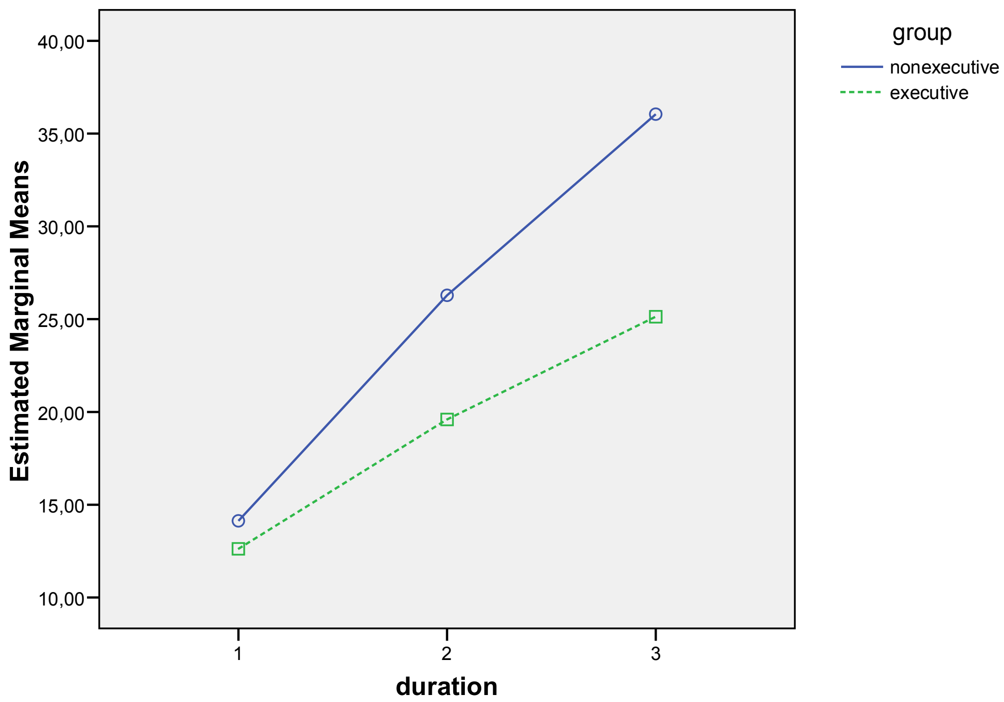

Figure 34. Raw Estimations for Exp-3 and Exp-4 (**1**: short, **2**: moderate, **3**: long)

Three independent samples t-tests (one-tailed for moderate) were conducted (by raw reproductions in sec) for the three duration lengths. They revealed a significant group effect for moderate ($t\ (1,20) = 2.360$, $p < .0167$) and longer durations ($t(1,20) = 3.242$, $p < .01$) indicating that estimations of moderate and long durations in Exp-4 (secondary executive task) were lower than estimations in Exp-3 (non-executive task). There was no difference in underestimation in Exp-4 as compared to Exp-3 for short durations ($p > .05$) (Figure 35).

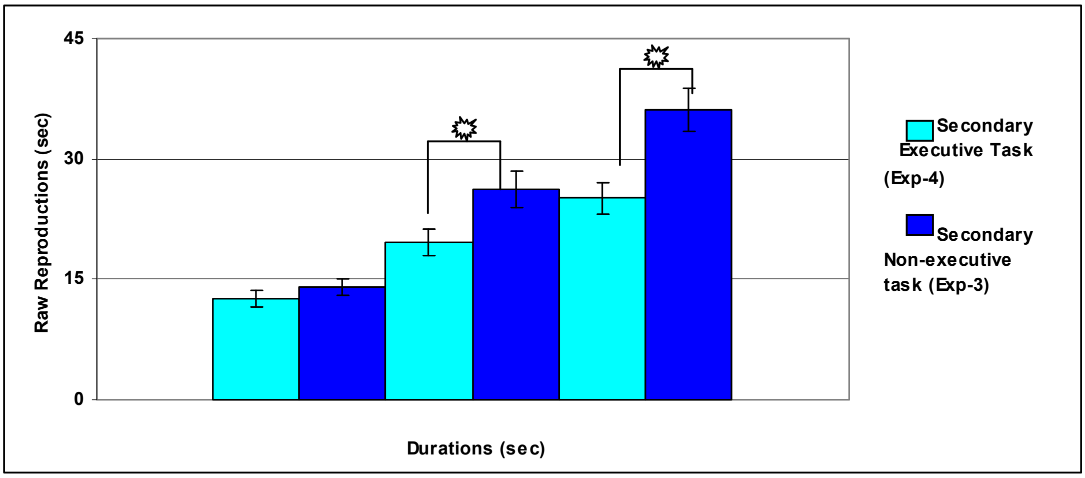

Figure 35. Raw Reproductions in Exp-3 and Exp-4

Moreover, ratio values of all durations n each experiment were combined and an independent samples t-test was conducted which confirmed that overall estimations in Exp-4 (0.68) were significantly lower than the estimations in Exp-3 (ratio= 0.87) ($t(1,20) = 2.333$, $p < .05$).

3.4.3. Discussion

Our explanation in previous discussion parts about distinct levels of underestimations for different durations can be supported by the results that we obtained in this experiment as well. Exp-4 was also a highly attention-demanding task. We found again that longer duration reproductions were underestimated more than relatively short intervals. The comparison of Exp-2 and 4 showed that the secondary executive task in Exp-4 consumes more attentional resources than the secondary temporal task in Exp-2. If we consider the huge effect size in Exp-4 as compared to the medium size effect in Exp-2 and the wider confidence intervals in Exp-4 as compared to Exp-2, we can conclude that a more attention demanding secondary task leads to stronger duration length effects on reproductions.

Another notable point is that also short durations (15 sec) in this experiment were underestimated as compared to the general control experiment (Exp-1). As stated before, the experimental manipulations we did affected only moderate and long durations in the previous experiments. Th short duration underestimation in Exp-4 is a good indicator that executive tasks in general consume relatively high amounts of attentional resources and lead to underestimations even at relatively short durations as well as in the multi-second scale of time perception. Our results indicate that the Simon task would be an appropriate task to be used as attention-demanding task in temporal duration judgement studies.

Absolute error/variance comparisons between duration lengths revealed that absolute errors were very high for the longer durations in Exp-4 as compared to variance in longer durations in this experiment. This should be the result of the maximum attentional resource demands of the executive task in this experiment. Therefore, we found a duration length effect on absolute error/ variance specific to this experiment. There was no such duration effect on this variable in the previous experiments. This should be taken as another sign of the profound underestimation in long durations during performance of an executive task. This is why mean reproductions in long durations were considerable different from actual durations while variance stayed approximately at the same level with the variance in long durations of the previous experiments.

Duration judgements in Exp-4 were significantly lower than in all the previous experiments. Our main hypothesis was to expect underestimation in this experiment as compared to Exp-3, in particular. Conflict resolution and executive demands in Exp-4 led to shorthened reproductions despite the same perceptual (rectangles at right or left) and motor activities (pressing right or left button) during the task with Exp-3.

Although we may expect that executive demands would have a more profound effect on duration judgements than a secondary temporal task (Exp-2), there is no evidence in the literature of this finding so far. Indeed, our results confirmed that duration reproductions in Exp-2 were significantly higher than reproductions in Exp-4. It should be noted that this was not due to the inefficient characteristics of the secondary temporal task to consume the attentional resources. Note that Exp-2 gave rise to significantly lower judgements as compared to the control experiment (Exp-1).

Last topic to discuss is the absence of the primary time estimation task effect on the secondary task (Simon task). Actually, it is already an expected result since the fact that Simon effect has a rigid nature. At least, we had an evidence for tendency of automatic spatial stimuli processing in Simon task is not affected by the concurrent temporal task. Statistical observations ,which is based on the presence/absence of a threeway interaction or not (e.g. Wiegand & Wascher 2005; 2007a; 2007b), did not reveal a difference in effect functions of “Simon only” and Simon task with a concurrent time estimation task. This finding is somehow different from the bi-directional interaction between temporal comparison task and duration judgments.

Actually since we do not have the overall baseline condition (which is a temporal comparison task without a duration judgment), we can only infer this effect from the difference between three durations. This can be explained by the different requirements of shorter durations and remaining ones in a temporal comparison task.

CHAPTER 4

GENERAL DISCUSSION

4.1. The Effect of the Secondary Executive Task on the Duration Judgments

In duration judgment studies, a dual-task condition is set up as to reveal how our time perception is affected by the concurrent secondary task. One of the aim of this thesis was revealing the effect of an executive task (Simon task) as a concurrent secondary task. If the two tasks (the executive non-temporal vs. the non-executive non-temporal tasks) differ in only their executive requirements and have identical visual stimuli and motor response activity, we could attribute the difference in interval reproductions to the executive nature of the task that is used. The executive requirement in our study was the conflict resolution. In the Simon task, the conflict between automatic response activation of the irrelevant spatial information and the relevant task rule (color information) should be resolved in order to produce correct response. Therefore, the executive task should consume more attentional resources than the non-executive task that contain no such conflict. Our results were in accordance with our hypothesis and we found that reproductions judged for executive task durations were significantly shorter than non-executive task estimations.

4.2. The effect of the Secondary Temporal Task on the Duration Judgments

The effect of a secondary temporal task was also confirmed in our results (see Exp-x). The dual-task condition of time perception studies is usually based on secondary non-temporal tasks. There are not many studies about secondary temporal tasks in the literature, though. One example is Cicogna et al.'s (2005) experiment about inserted time-based and event-based prospective tasks within a main time-based prospective duration task. They used the production method with a larger scale (minutes) and found a facilitation effect of the inserted time-based task on the primary time-based task which means that the secondary temporal task helped with the correct production of the temporal duration in the main task. Our results, however, indicate an interference effect of the secondary temporal task on primary duration judgments. The reason of the opposite results may lie in the different estimation methods that are used in both experiments. As already stated before, production - as in Cicogna et al. (2005) - and reproduction – as used here - give rise to different effects on estimations. Participants judge durations as longer when they are asked to perform a secondary task in the production method. This is because their attentional resources are used for the secondary task and fewer pulses flow through the attentional gate to the accumulator. Therefore, subjects tend to wait longer to stop their estimation in the production method to reach enough number of pulses for accumulation. On the other hand, if a person performs a secondary task during the given duration to be reproduced later, they experience the time shorter because of the same reason, that is, less accumulated pulses, in the reproduction method. They, in contrast to the subjects in a production experiment, do not wait longer to stop their estimations since they experience the duration as short. Our finding is therefore not incompatible with Cicogna et al.'s (2005) results. Moreover, we can claim that the facilitation that was found in this study is the consequence of the attentional resource consumed for the secondary time-based task. Again, as stated before, all kinds of duration estimations have a tendency towards underestimation compared to objective time. So, in a production method, it is expected that if a secondary task consumes some attentional resources, the production of the main task would be longer and therefore close to the objective duration. This could be named as a facilitation but we should indicate that primary and secondary time-based prospective tasks share attentional resources from a common pool. This could be called an interference effect as well. Our results support this resource sharing view in addition to the novelty of using a secondary temporal task with a duration reproduction method.

4.3. The Duration Length Effect

Interestingly, we found a duration length effect in only those experiments that include a high amount of attention demanding secondary tasks, namely Exp-2 and Exp-4). This effect was marginally significant in Exp-3 in which non-executive secondary task was not so attention demanding. The duration length effect denotes the situation that longer durations are more underestimated than shorter durations. There is no assumption that resource allocation decreases with duration increase in attentional models (Block & Zakay, 1997). However, there is some evidence (e.g. Nigro et al., 2002) indicating better performance of time-based prospective judgments at shorter durations (Block & Zakay, 2006). This was also the case for our results. We found no underestimation when comparing the effect of temporal comparison and Simon tasks at short durations (15 sec). Therefore, our results suggest that the more profound underestimation at longer intervals may depend on the amount of attentional resource demands of the secondary task. Absence of an overall duration effect in Exp-1 (control) and marginally significant length effect in Exp-3 (non-executive) might be the result of undisturbed temporal information processing. Therefore, these results may lead us to the conclusion that both duration length increase and secondary task attentional demands give rise to an underestimation of task duration. Although we cannot tell to what degree these two parameters affect duration judgments within the scope of this thesis, we can claim that if we had a shorter duration than the shortest duration that we used with the same executive task (Simon task-Exp-4), we would probably see no underestimation at this new shorter interval either. Unfortunately, it was not possible to include more duration lengths to cover a wider range of prospective judgments in this study. However, using three intervals already revealed a duration length effect in the presence of high attentional resource demanding tasks (Exp-2 and Exp-4).

4.4. Interaction Between Temporal Comparison and Duration Judgment Tasks

We will continue discussing the interaction between the secondary temporal task and the main duration judgment in Exp-2. There was no duration length effect in Exp-1, which shows that all duration lengths were judged approximately in the same way and there was no difference in their underestimation level. On the other hand, the temporal comparison task used in Exp-2 as a secondary task leads to a duration length effect which means that shorter durations were less underestimated than longer durations. We discussed this result in general in the previous paragraphs by stating that secondary tasks with a high amount of attentional demands may lead to longer durations being affected much more than shorter durations. We considered the evidence from relevant experiments (e.g. Nigro et al., 2002) suggesting that time- based prospective judgments may be better at shorter intervals and time-based paradigm have a tendency to converge with event-based paradigms at longer intervals (e.g. Block & Zakay, 2006). However, there might be another specific explanation for the fact that there is an interaction between duration length and experiments (Exp-1 vs. -2). As stated in the results part of the thesis, the scores of the temporal comparison task (in Exp-2) were decresing with decreasing duration length. Shorter durations had a secondary temporal task within a 1-3 sec range, moderate had a 2-6 sec range and longer ones had a 3-9 sec range. Baddeley (1997) proposed that the rehearsal loop of working memory has a range of approximately 2 sec. Moreover, Lejeune (1998) stated that duration judgments needs sustained attentional resource allocation. In the light of this information, we would expect shorter intervals to be less underestimated because there is no need to allocate sustained attention for the secondary task performance (since the task can be performed within the range of working memory) and there will be more resources avaliable for the main duration judgments. Some ranges of the moderate interval secondary task overlap with the workig memory extension (2 sec) and longer intervals certainly need sustained attentional resource allocation. Indeed, we saw a hierarchy in temporal comparison scores that is higher in longer durations and lower in shorter durations indicating that attentional resources are consumed by the secondary task in moderate and long intervals but not in short ones.

4.5. Attentional Resource Allocation Hierarchy of the Secondary Tasks

We have conducted four experiments which revealed an almost perfect hierarchy between the secondary tasks according to their attentional resource demands. The secondary tasks are characterized below in terms of the two features +/- temporal; +/- executive.

(+) executive/ (-) temporal (Exp.-4) > (-) executive/ (+) temporal (Exp-2) ≅
(-) executive/ (-) temporal (Exp-3) > (-) executive / (-) temporal (Exp-1)

In Exp-1 the secondary task was very simple and did hardly consume any attentional resource. As a consequence, we found duration judgments close to the intervals' objective length. Then there are the secondary temporal task (Exp-2) and secondary non-executive task (Exp-3) within the hierarchy of the secondary tasks. Although judgments in Exp-3 were not shorter than in the control experiment (Exp-1), results were marginally significant. Of course, the non-significant result of our non-executive task is not a strong evidence for the failure of the non-temporal tasks in general. Our main aim was to design a task as a control case of the last experiment. The simple and regular structure of the task may not have consume sufficient attentional resources to yield a significant result. On the other hand, the secondary temporal task (temporal comparison) gave rise to significant underestimation compared to Exp-1. We can claim that both secondary tasks in Exp-2 and Exp-3 may affect duration judgments to approximately the same degree. Finally, the executive task in Exp-4 leads to the most profound effect on temporal judgments within all experiments. According to one of our hypotheses, it was an expected result to find a significant difference between Exp-3 and Exp-4. Moreover, we found that the duration estimations were significantly shorter for secondary executive task than the estimations for secondary temporal task. Although this comparison was not one of our hypotheses and the two experiments had different designs, we can suggest that the non-temporal executive task (Simon task) has a stronger influence on time perception than the temporal comparison task.

4.6. Study Limitations

One limitation of the present study was the design of the non-executive non-temporal task (Exp-3). Since our main aim was to have a baseline experiment for the last experiment, we prefered to use exactly the same perceptual and motor activity, however, without any executive requirements. Therefore, we had a relatively easy task within all types of non-temporal non-executive tasks. Although we achieved what we hypothesized with this design, we could not see the effect of the non-temporal non-executive task (Exp-3) compared to the control experiment (Exp-1).

CHAPTER 5

CONCLUSION

In this study, we investigated the effect of various secondary tasks on duration judgments. The main aim of the thesis was to find out how the duration estimations were changed with a concurrent non-temporal executive task (Exp-4) and with a temporal non-executive task (Exp-2). For this purpose, we did not only use one control experiment including an (almost) empty time interval (Exp-1). Instead, separate control experiments were conducted for both non-temporal executive (Exp-3) and temporal comparison task (Exp-1). Therefore, we could see the effects of just executive or temporal comparison requirements on attentional resource allocation.

Experiment 1 was the most basic control experiment in which participants were asked to judge an empty interval. Subjects were simply asked in which sequence the backgorund colors appeared after the given durations in the main task. Therefore, we obtained an identical experimental design as compared to Exp-2, except the attentional requirements.

In Experiment 2, we administered a duration judgment task with a secondary temporal task. subjects were asked to judge the relative length of the three background colors in the concurrent temporal comparison task. Therefore, we could compare Exp-2 with Exp-1 and see the difference that was caused by attentional resource allocation for the temporal comparison task. Indeed, our design was succesful and revealed that durations were underestimated more when the participants were performing the temporal comparison task as compared to the most simple concurrent secondary task in Exp-1.

A further aim was to obtain another baseline in Experiment-3, specific to our last experiment (Exp-4). Subjects were asked to judge the durations while they were responding to a relatively easy concurrent task. The task was a non-temporal non-executive task that requiree active participation, however, without executive demands.

In Experiment 4, an executive task (Simon task) that requires conflict resolution was used. As expected, we found that high attentional demands resulted in the underestimation of the main durations, as compared to Exp-3. On the other hand, there was no significant effect of the duration judgment task on the Simon task which we assessed by comparing the Simon task data in this study with the data that had been obtained in our previous Simon task studies (Duzcu & Hohenberger, 2009).

Moreover, we found a duration length effect that was significant for only the experiments with high attention demanding secondary tasks (Exp-2 and Exp-4). This effect was marginally significant for moderately attention demanding task (Exp-3) and there was obviously no effect in the empty time interval (Exp-1). Although there is some evidence indicating that longer durations are more underestimated than shorter ones in prospective judgments, our results exhibited a new parameter, that is, dependency of the duration length effect on attentional requirements of the secondary tasks.

Another interesting result was to see the effect of sustained attention allocation on the temporal comparison task (Exp-2). Our results indicate that the accuracy of the temporal comparison was lower at shorter durations. Since the durations (which are compared within the main duration) were in the range of working memory capacity (see Baddeley, 1997) at shorter duration condition, there should not be any additional sustained attention allocation for the comparison of interpolated durations. Therefore, participants' scores were lower at short durations. Moreover, no sustained attention allocation to the secondary task in short durations spared resources for the main duration judgments which led to almost veridical reproductions close to the objective length.

On the whole, we obtained evidence for the fact that an inserted time-based prospective reproduction task consumes part of the avaliable attentional resources which leads to the underestimation in the main time-based judgment. Moreover, this thesis allowed us to see the effect of an executive task which is a valuable addition to the set of commonly used dual-tasks in the literature. Finally, we gained insight into the duration length effect which depends on the level of attentional resource demands of the secondary tasks.

As a future study, the same design as in Exp-2 may be conducted with a production method in order to gain a better understanding of interference/facilitation effects of secondary time-based tasks. Secondly, it would be beneficial to cover more duration lengths in order to have a wider range and better explanation for prospective duration judgments.

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APPENDICES

APPENDIX A: BACKGROUND COLOR SEQUENCE SHEET

Time Reproduction / Empty Time (Experiment-1)

Her bir trial içinde arka fondaki renklerin sırasını **1, 2** yada **3** yazarak belirtiniz. Beyaz fonu belirtmenize gerek yok.

	Sarı Fon	**Kırmızı Fon**	**Mavi Fon**
Practice-1			
Practice-2			
Practice-3			
Trial 1			
Trial 2			
Trial 3			
Trial 4			
Trial 5			
Trial 6			
Trial 7			
Trial 8			
Trial 9			
Trial 10			
Trial 11			
Trial 12			
Trial 13			
Trial 14			
Trial 15			

APPENDIX B: BACKGROUND COLOR RELATIVE DURATION SHEET

Time Reproduction /Secondary Temporal Task (Experiment-2)

Her bir trial içinde arka fonlardan hangi renklerin en uzun, orta yada en kısa sure göründügünü **U, O** yada **K** yazarak belirtiniz.

	Sarı Fon	**Kırmızı Fon**	**Mavi Fon**
Practice-1			
Practice-2			
Practice-3			
Trial 1			
Trial 2			
Trial 3			
Trial 4			
Trial 5			
Trial 6			
Trial 7			
Trial 8			
Trial 9			
Trial 10			
Trial 11			
Trial 12			
Trial 13			
Trial 14			
Trial 15			