Influence of Visual Grouping and Temporal Attention on Temporal Resolution: Evidence from a Temporal Order Judgment (TOJ) Task

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Abstract

Time appears to pass in slow motion, according to subjective reports of people who have been involved in car accidents or other extreme situations. Previous research attributed *time's subjective expansion* (TSE) to the engagement of attention and its influence on the amount of perceptual information processed (Tse et al., 2004). We propose that two processes contribute to slow motion perception in TSE. One is grouping attributes of the scene into wholes and segregating them from their background. Another is an increased amount of attention to temporal properties of the extreme scene. The present thesis investigates the influence of visual grouping and temporal attention on temporal resolution in a less dramatic situation to reveal whether novel or important events perceived in slow motion may indeed be processed in greater depth per unit of objective time than are normal events as assumed by Tse et al. (2004). A temporal order judgment (TOJ) task was applied at 50 participants to measure temporal resolution. A grouping effect was induced by use of a bar stimulus to unify the background on which two light-emitting diodes (LEDs) flashed. Two squares, one forming the background of each separate LED, comprised a control condition for the unified one just described. Attention to temporal properties of the background stimuli was induced by the use of abrupt stimuli which appeared with a specific temporal interval prior to the onset of either LED. In the control condition, the background stimuli were displayed persistently throughout the whole trial rather than abruptly.

Temporal resolution was significantly higher when either visual grouping or temporal attention induced by abrupt stimuli was present and highest when both were combined. This novel finding provides evidence that multiple processes are involved leading to increased temporal resolution during TSE.

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List of Abbreviations

2AFC	Two-Alternative Forced Choice
AM	Apparent Motion
ANOVA	Analysis of Variance
BIT	Binary Digit
EEG	Electroencephalography
EHI	Edinburgh Handedness Inventory
fMRI	functional Magnetic Resonance Imaging
Hz	Hertz
IPS	Inferior Intraparietal Sulcus
ISI	Interstimulus Interval
ITI	Intertrial Interval
LCD	Liquid Crystal Display
LED	Light Emitting Diode
lm/m^2	Illuminance in lux
MEG	Magnetoencephalography
M	Mean
ms	Millisecond(s)
N	Newton
PD	Parkinson's Disease
RT	Reaction Time
s	Second(s)
SOA	Stimulus Onset Asynchrony
TOJ	Temporal Order Judgment

TOT	Temporal Order Threshold
TSE	Time's Subjective Expansion
USB	Universal Serial Bus
VA	Visual Angle
VSTM	Visual Short-Term Memory

Chapter 1: Introduction

1.1 Temporal Resolution: Influential Factors and Dependencies

Time appears to stop, according to subjective reports of people who have been involved in car accidents or other extreme situations. Imagine the following situation: you are driving along a highway on a motorbike, planning to do a U-turn. You see a car in the opposite lane driving in your direction, but it is so far away that you have enough time to execute the maneuver. You slow down, you have stopped, and then it happens: you stall the engine. Immediately you try to restart the engine, but it doesn't work anymore. Standing in the middle of the highway, your bike across both lanes, you check again for the car moving in your direction, and you realize that it is approaching much faster than it appeared to be several seconds before. The car is already so close that it wouldn't be able to stop before reaching you. Now you have two choices: leaving your motor bike behind, you will (1) run to the left side, or (2) run to the right side of the highway. The car starts zigzagging and you realize that the driver is unsure about whether to pass you on your left or on your right side. You feel that you do not have enough time to escape from the road. Your attention is captured by that car coming closer at high speed. The whole scene surrounding the car becomes visually faded. Time appears to slow down dramatically, and the car seems to move in slow motion.[1]

Are we really able to see the world in slow motion in extreme situations like this? Can time's subjective expansion (TSE) be attributed to the interference of

[1] The author would like to note that this small narration is based on one of his own experiences.

attention and its influence on the amount of perceptual information processed (Mattes & Ulrich, 1998; Tse, Intriligator, Rivest & Cavanagh, 2004; Xuan, Zhang, He & Chen, 2007)? In other words, does TSE lead to higher temporal resolution? And if so, can we objectively measure it? Or is it just an illusion based on an erroneous retrospective evaluation of memory? Is it the case, for example, that extreme events become more associated with intensive memory, and the more memory one has of a specific event, the longer it is interpreted to have lasted (Eagleman, 2008)? Before these questions will be further analyzed, the phenomenal experience captured in the above example will be summarized.

First, a salient object captures our attention. The color, wheels, driver and all the other features which are associated with the car become visually grouped into one coherent object, before it is identified as a car moving in our direction. We segregate the car with its boundaries from its background. Second, our attention becomes more focused on that object. The amount of information which we are processing with respect to the car rapidly increases. At the same time, less information is processed about the background. A shift of our attentional resources has taken place. Third, time seems to subjectively expand as though our temporal resolution changes.

Visual grouping, attention, and their influences on temporal resolution will be investigated under far less dramatic situations within this thesis. In the following sections, these processes will be individually summarized, followed by the purpose and hypothesis of this study. Although the author’s motivation for this study was to address the processes involved in TSE, it is acknowledged that this study mainly provides a step in understanding the perceptual and attentional properties associated with increased temporal resolution of visual perception.

1.1.1 Temporal Resolution

In psychophysics, temporal resolution refers to the ability to perceive and discriminate events in time. There are different indicators of temporal resolution. The detection threshold is the level of intensity (e.g. luminance, duration, size, frequency) with which a subject is able to detect a stimulus. The discrimination threshold between two stimuli represents the magnitude of the difference required to distinguish them. The temporal order threshold (TOT) is the smallest interval necessary to correctly judge the temporal order of two stimuli. The estimation of the TOT is very common in psychophysical experiments which investigate temporal resolution. In the present study, a visual temporal order judgment (TOJ) task was used. The minimal interstimulus interval (ISI) which is required for correct visual TOJ is usually situated in the time domain of approximately 20 to 40 milliseconds in normal subjects (Hirsh & Sherrick, 1961; Pöppel, 1997).

1.1.2 Visual Grouping

To navigate in the world, our visual system needs to organize complex visual scenes into distinct units, which can be attended individually (Xu & Chun, 2007). Object recognition would be impossible without having this ability. Before an object can be identified, it also needs to be separated from its background. The process of perceptual segregation groups the visual scene into objects and their backgrounds (Treisman, 1982).

The phenomenology of perceptual grouping was first studied in detail in Gestalt psychology (Wertheimer, 1922, 1923). Different factors like similarity, proximity, common fate (elements moving in one direction are perceived as a unit), and good continuation (the mind continues visual and auditory patterns) do affect the way distinct elements are grouped into wholes, according to Gestaltists. These principles are called 'unit forming factors'. It has been suggested that these factors maximize the chance of putting together elements of one object and separating elements of different objects, and that the perception of such factors evolved for this reason (Treisman, 1982).

Beck (1972) found that grouping by similarity is a process which happens prior to focusing attention, and patterns which are easily discriminated will mediate visual grouping. This finding is consistent with the feature-integration theory of Treisman and Gelade (1980) suggesting that visual grouping is an early, pre-attentive process.

1.1.3 Attention

Attention is another important cognitive process that works together with visual grouping so that people can navigate in and interact with the world. It enables one to concentrate on relevant aspects of the environment while fading out unimportant ones. Attention can be allocated on time (temporal attention) or space (spatial attention); it can be focused (focused attention) or divided (divided attention), or a product of pre-conscious processing. Moreover, it can be induced by external (exogenous) or internal (endogenous) cues (Pashler, 1998). A complete enumeration of all the kinds of attention is outside the scope of this thesis. However, there are two qualities of attention which are important to mention with respect to this investigation. Attention can enhance temporal resolution (Bausenhart, Rolke, & Ulrich, 2008; Chica & Christie, 2009; Correa, Sanabria, Spence, Tudela, & Lupianez, 2006; Stelmach & Herdman, 1991) and spatial acuity (Mackeben & Nakayama, 1993; Shiu & Pashler, 1995) of the visual system. Given the abovementioned effects of attention, extreme events leading to slow motion perception may be processed with enhanced temporal resolution (Tse et al., 2004).

1.2 Purpose

The purpose of this study is to investigate the influence of visual grouping and attention to temporal information (temporal attention) on temporal resolution in healthy, right- and left-handed participants with a TOJ task. Following the general experimental procedures and design, the hypotheses will be elaborated.

A novel experimental design was used, which includes spatial-unified (bars) and non-unified (separate squares) stimuli which appeared either in an abrupt or persistent manner as background objects on which two light-emitting diodes (LEDs) flashed (see Figures 8 and 9). Two mixed-stimuli conditions were added to the design (alternating the bars and squares) where the stimuli appeared either persistently or abruptly to investigate whether possible effects in the blocked conditions survive the necessity to switch between them from trial to trial within a block. A so-called grouping effect was to be induced by use of the bar stimulus as an exogenous cue to unify the background on which the two LEDs flashed on that condition. This type of stimulus has been used in previous research for visual grouping of distinct objects (Xu & Chun, 2007). Two squares, one forming the background of each separate LED, comprised a control condition for the unified one just described. Attention to temporal properties of the background stimuli was induced by the use of abrupt stimuli which appeared with a specific temporal interval prior to the onset of either LED. Bausenhart et al. (2008) used this kind of experimental manipulation with constant foreperiods to influence temporal attention in their subjects. In the control condition, the background objects were displayed persistently throughout the whole trial rather than abruptly. A final manipulation was a between-subjects factor in which participants were assigned to one of two experimental groups which received different instructions. Participants in one group were asked to be certain of which LED appeared first before making any judgments on temporal order (Wait instructions). Participants in the other group were instructed to perform the task without such deliberation, as quickly as they could even if they sometimes had to guess (Standard instructions). The aim of including the different instructions was to assess whether some early information processing associated with TOJs might result in different effects on TOTs than judgments made with deliberate thought about temporal order.

In sum, the aim of this study is to examine if visual grouping, temporal attention, or both processes, affect performance in TOJ. The involvement of the early and late information processing in TOJ is investigated by the use of different instructions. The experimental results are analyzed with the aim of assessing evidence consistent with improved temporal resolution in slow motion perception during TSE, as suggested by Tse et al. (2004).

1.3 Hypotheses

The threefold hypotheses of this study are as follows:

i.) TOTs will be lower thus, temporal resolution will be better when visual unified background stimuli are displayed compared to non-unified stimuli, consistent with previous research showing that grouped objects are easier to perceive than ungrouped ones;

ii.) TOTs will be lower when background objects are abrupt compared to persistent, consistent with previous research suggesting that temporal resolution can be improved by attention to temporal information;

iii.) TOTs will be lowest when both above factors are combined and highest when both are absent, consistent with the notion that visual grouping and temporal attention enhance temporal discrimination.

Chapter 2: Review of the Literature

2.1 Measuring Temporal Resolution with Temporal Order Judgment: Conceptualizations, Dependencies and Applications

One of the most common methods to measure temporal resolution is the temporal order judgment (TOJ) task which determines the temporal order threshold (TOT). Several studies have shown that the TOT seems to be invariant for visual, auditory, tactile and two-modality stimuli in normal subjects (Hirsh & Sherrick, 1961; Kanabus, Szelag, Rojek, & Pöppel, 2002; Swisher & Hirsh, 1972). Pöppel (1997) suggests a central timing mechanism which is responsible for TOJ across all sensory modalities. Various experiments have provided neurophysiological correlates for this mechanism. Joliot, Ribary, and Llinas (1994) proposed neuronal oscillations in the 40 Hz gamma band as an underlying timing mechanism which creates basic temporal units of perception, and provides discrete processing of information. Pöppel and colleagues (Pöppel, Schill, & von Steinbuchel, 1990; Pöppel, 1997) suggested that neuronal oscillations, each lasting around 30 ms, could represent these fundamental processing units, and that perceived events within one unit are treated as co-temporal. Other studies proposed rhythmic brain activity in the 40 Hz gamma band as a mechanism that could provide fundamental temporal building blocks in cognitive and sensory processing (Basar-Eroglu, Struber, Kruse, Basar, & Stadler, 1996; Gray, Konig, Engel, & Singer, 1989; Schwender et al., 1994).

Other studies reported that TOJ appears to be due to feature-specific discrimination mechanisms. McFarland, Cacace, and Setzen (1998) showed that the physical properties (size, color or orientation for visual stimuli; frequency or sound pressure of auditory stimuli) of the stimuli which were applied in their experiment significantly influenced subjects' temporal resolution. TOTs varied with stimulus dimension, being lowest for auditory frequency, intermediate for size, orientation, and auditory level, and highest for color. Moreover, previous research has shown that TOTs were critically dependent on the degree of spatial separation of the presented stimuli (Fendick & Westheimer, 1983; Westheimer & McKee, 1977; Westheimer, 1983).

Fink, Ulbrich, Churan, and Wittmann (2006) suggested two different processing mechanisms which may underlie TOJs. One was thought to be a more independent, feature-specific mechanism which processes the temporal order of two different tones, and the other, a central, modality-independent timing mechanism which contributes to TOJ with click sound, colour and position of stimuli.

In a study by Zackon, Casson, Zafar, Stelmach, and Racette (1999) the role of subcortical processing in TOJ was investigated with the presentation of endogenous and exogenous cues. They found that attention to exogenous stimuli was based on subcortical processes which facilitated rapid shifts in attention, while voluntary directed attention induced by endogenous cues was more associated with cortical processes.

Much research has been conducted on the relation between TOJ and reaction time (RT). The results seem to be as controversial as the very conceptualization of the mechanism underlying TOJs. In an experiment determining the perception–action relationship on a trial-by trial basis, Cardoso-Leite, Gorea, and Mamassian (2007) found evidence that TOJs and RTs are based on a common processing system. However, other studies showed that TOJs and RTs appear to be based on two different processing systems which are not related to one another (Jaskowski, 1993; Jaskowski, 1996; Miller & Schwarz, 2006).

The influence of age and gender on TOJ was investigated in studies by Szymaszek and co-workers (Szymaszek, Szelag, & Sliwowska, 2006; Szymaszek, Sereda, Pöppel, & Szelag, 2009). They found that TOTs in the auditory domain were lower in the young than the elderly and in male than female subjects. Moreover, TOTs were lower for tones than clicks. A recent study by Kolodziejczyk and Szelag (2008) extended these findings to centenarians, who showed significantly higher TOTs than elderly and young subjects. A slowing of information processing in older people was proposed as a possible explanation of this effect.

In clinical neuropsychology, TOJ was investigated in patients with Broca's aphasia (Szelag, von Steinbuchel, & Pöppel, 1997). This study revealed that Broca's patients who suffered language deficits from brain lesions developed temporal discrimination strategies which were more associated with mental counting than with strategies based on automatic temporal integration. Von Steinbuchel, Wittmann, Strasburger, and Szelag (1999) found that auditory TOJ is impaired in aphasia patients with cortical lesions of the left hemisphere. A recent study by Tommerdahl, Tannan, Holden, and Baranek (2008) showed that TOJs in patients with autism were not impaired in the presence of synchronized conditioned stimuli. Another study on patients with dyslexia showed deficits in TOJs both when two stimuli were presented laterally, and when the stimuli were vertically aligned (Jaskowski & Rusiak, 2008). The performance on TOJ in patients with Parkinson’s disease (PD) was investigated in a study by Lewald, Falkenstein, and Schwarz (2006). They showed with a crossmodal TOJ task that PD patients had delays in auditory processing compared to visual processing. Thus, intact temporal order judgments are clearly important in normal perceptual and cognitive processing.

With respect to the possible neural mechanisms underlying TOJs, some studies have assessed issues related to hemisphere laterality and hand dominance effects. For example, a study by Corballis (1996) on hemispheric interactions found no hemifield difference in TOTs with unilateral presentation of spatially separated stimuli. Thus, it was suggested that neither hemisphere is uniquely specialized for TOJ. The influence of arm crossing on TOJ was investigated by a study of Yamamoto and Kitazawa (2001). They demonstrated that the subjective temporal order of two tactile stimuli which were delivered to the subjects' hands was highly depended on weather the arms were crossed or not. Subjects began to invert the temporal order of the two stimuli at relatively short intervals below 300ms. Similar results could be found in an extended study with crossing sticks (Yamamoto & Kitazawa, 2002). A study by Wada, Yamamoto and Kitazawa (2004) found that handedness affects performance in TOJ. Right-handed subjects showed lower TOTs than left-handed subject in both uncrossed and crossed arm conditions in a tactile TOJ task. This finding was thought to be due to a stronger hemispheric lateralization in right- than left-handed subjects.

2.2 Interactions between Visual Grouping and Attention

Kahneman and Henik (1977) proposed a hierarchical model for the relation between attention and perceptual grouping, where attention is first allocated to a group as a whole, and subsequently to elements within a group. In their study they investigated selective attention in relation to the degree of spatial segregation or mixing of blue and red letters. Participants were instructed to recall the red letters only. They performed better when the letters were grouped compared to a checkerboard arrangement. This finding is especially interesting with regard to the hypothesis of the present study, suggesting that attention might more effectively be focused on multiple relevant items if these are spatially grouped.

In her review of feature binding, object perception and attention, Treisman (1998) summarized that attention plays an important role in perceiving and integrating elements of a scene to represent meaningful objects. Thus, a close relationship appears to exist between visual grouping and attention.

Kimchi and Razpurker-Apfeld (2004) found evidence for a multidimensional relationship between grouping and attention. In their experiment, two successive displays were briefly presented to the subjects. Each of them comprised a central target square surrounded by elements. The subjects were instructed to judge whether the two targets were the same or different. The arrangement of the background stimuli stayed the same or changed, independently of the targets. The experiment was comprised of different conditions where background elements were grouped into columns and rows, a shape (a triangle/arrow, a square/cross, or a vertical/horizontal line), by colour similarity, or by a shape with no other elements in the background. The influence of the background on the target ‘same–different’ judgments was measured. It was found that when background stimuli were grouped into rows and columns by colour similarity and into a shape when no segregation from other stimuli was involved, same-different judgments were relatively good. No background grouping could be found when subjects were required to resolve figure–ground relations for segregated units, as in grouping into a shape by colour similarity. Thus, it was suggested that grouping is the result of a multiplicity of processes that vary in their attentional demands, while the individual attentional demand can be described as a function of the processes which are involved in grouping. The results of that study imply a multidimensional relationship between visual grouping and attention.

Moore and Egeth (1997) found that Gestalt grouping can occur under conditions of inattention. In their study, participants were instructed to report which of two briefly displayed horizontal lines was longer. The lines were formed by dots in the background using the Ponzo illusion or the Müller-Lyer illusion, where one line appears to be longer than the other one, even though both are the same length. It was found that despite inaccurate reports of what the briefly presented patterns were, participants' discriminations of the line-lengths were clearly affected by the 2 illusions. Thus, it was suggested that Gestalt grouping can occur pre-attentively, but that attention may be required to encode the results in memory. Especially relevant to the present study is their suggestion that substantial perceptual organisation precedes the allocation of attention within a visual scene.

Vidal, Chaumon, O'Regan, and Tallon-Baudry (2006) suggested a common neuronal implementation mechanism for visual grouping and focused attention: gamma-band oscillatory synchrony. In their study they found that gamma oscillations which were related to attention appeared in the low gamma band (44–66 Hz), while gamma oscillations which were related to grouping appeared in the high gamma band (70–120 Hz). Their experiment comprised a delayed matching-to-sample task where subjects were presented with displays of eight bars. The orientation of either four bars (half the display) or eight bars (the whole display) had to be stored in visual short-term memory (VSTM). Subjects were instructed to detect whether the orientation of one of the previously memorized bars had changed when the test stimulus appeared. Four different conditions were applied. Stimuli used for grouping gave rise to the perception of a homogeneous group of eight items or to the perception of two groups of four items. The stimulus used for attention (fixation cross) prompted the subject to focus his/her attention on either a subset of the display (focused attention) or on the whole display (distributed attention). Magnetoencephalography (MEG) signals were recorded while stimulus manipulations were done in all conditions. It was found that grouping-related gamma oscillations were present in the high gamma-band (70–120 Hz) at central occipital locations. Gamma oscillations related to attention appeared as an additional component in conditions where attentional focusing was required in the low gamma-band (44–66 Hz) at parietal locations. Thus, gamma-band oscillatory synchrony was suggested as a common neural implementation mechanism for both grouping processes and focused attention. Moreover, it was suggested that coherent percepts are more likely to catch attention than incoherent ones, which is in line with most of the studies presented in this section.

2.3 Interactions between Visual Grouping and Temporal Resolution

Visual grouping is a binding process which is important in organizing complex visual scenes into discrete units that can be selectively attended to and processed. Xu and Chun (2007) found that grouped visual elements are easier to perceive than ungrouped ones after parietal brain lesions. Subjects were asked to retain in visual short-term memory (VSTM) the identities of shapes which were either grouped or ungrouped by background objects (bars). The stimuli were presented briefly followed by a delayed test display. Results of the study revealed that grouped shapes elicited lower levels brain activation with functional magnetic resonance imaging (fMRI) than ungrouped shapes in inferior intraparietal sulcus (IPS). Thus, it was suggested that grouped shapes allow more object shape information to be passed onto later stages of visual processing and therefore, were easier to perceive than ungrouped ones after parietal brain lesions. This finding indicates that visual grouping facilitates the processing of temporal information in the visual system.

In contrast, another study, Nicol and Shore (2007) found evidence that perceptual grouping impairs temporal resolution. In their experiment, the subjects performed a visual TOJ task in which two U-shaped stimuli were presented in an arrangement that either encouraged visual grouping (open ends of the U-stimuli facing each other) or did not (open ends of U-stimuli facing opposite directions). Performance in TOJ was better when the two targets formed two objects than when they formed one.

2.4 Interactions between Attention and Temporal Resolution

2.4.1 Spatial Attention and Temporal Resolution

The influence of spatially directed attention on temporal resolution was investigated by Stelmach and Herdman (1991). They found that the speed of information processing in the visual system was increased when subjects' attention was directed to a specified location. In their study, subjects were instructed to judge the temporal order of two stimuli while directing attention toward one of the stimuli or away from both stimuli. It was found that the attended stimulus appeared to occur before the unattended one, despite equal stimulus onset times. Thus, it was suggested that the direction of attention influences the perception of simultaneity and that the perceptibility of very fast events like flicker and jerky motion may be greater at attended locations than at unattended locations. These results imply that spatially directed attention influences temporal perception.

Mattes and Ulrich (1998) found evidence that the perceived duration of attended stimuli appears to be longer than that of unattended ones. In their experiment the subjects' attention was directed by external cues to one of two possible stimulus sources which appeared in either the visual or the auditory domain. Stimuli in the attended modality were rated as occurring longer than stimuli in the unattended modality. Moreover, this finding applied also to stimuli which appeared at different locations within the visual field. Thus, it was suggested that directed attention prolongs the perceived duration of a stimulus.

Galera, Cavallet, von Grünau, Caserta, and Panagopoulos (2006) showed that attentional resources are more concentrated inside a framed area than outside it. In their study, a TOJ task was used to measure the differences in the concentration of attentional resources inside and outside an attended area. Two experiments were conducted where subjects were instructed to judge which of two successive letters was presented first or second. One of the letters was presented randomly inside a delimited area which was framed by a rectangle. In both experiments, judgments which have been done on the stimulus presented inside the delimited area were more accurate compared to those made on the stimulus presented outside the area. Therefore, it was suggested that attentional resources are more concentrated inside a delimited area than outside it.

Chica and Christie (2009) recently found that spatial attention does improve temporal discrimination. In their study, subjects performed better in a temporal-resolution task under induced exogenous attention. Subjects were asked to report whether they perceived very short temporal gaps in the appearances of either cued, uncued, or neutral stimuli. RTs were controlled by constraining the responding time giving the subjects a limited amount of time to respond. Results of the experiment revealed that the temporal gaps were easier perceived on cued trials as compared with neutral trials. Subjects also did better in cued trials compared with uncued trials. Thus, it was suggested that, under certain circumstances, exogenous attention does improve temporal resolution.

2.4.2 Temporal Attention and Temporal Resolution

Recent research has shown that temporal attention improves temporal resolution. Bausenhart et al. (2008) used an experiment with a constant foreperiod design to show that temporal resolution can be improved by temporal preparation. In their experiment, subjects viewed two spatially adjacent dots preceded by a warning signal with a foreperiod of either 800 ms or 2400 ms. The percentage of correct responses in a TOJ task was higher when participants were cued by warning signals to predict the stimulus onsets more precisely. Moreover, shorter foreperiods were associated with improved TOJ.

Another study which shows that temporal attention improves temporal resolution was done by Correa et al. (2006). They used an explicit temporal cuing paradigm of selective attention where participants judged which of two visual stimuli had been presented first. A temporal cue indicated a relevant moment in time to which subjects attended as preparation for the TOJ. Temporal resolution was improved by attending to that relevant moment as indicated by the temporal cue.

2.5 Summary

The TOJ task is a highly common and precise method used in science to measure human temporal resolution ability. The influence of either attention or visual grouping on temporal resolution was investigated in various studies. Most provide evidence that spatial and temporal attention enhance temporal resolution. There is more controversy over whether visual grouping enhances temporal resolution. However, research has shown that visual grouping helps to allocate attention to elements within a specific area, and that both rely on a common neuronal implementation mechanism.

In the following chapter, a novel experimental design based on the TOJ paradigm will be introduced. It was applied to investigate the hypothesis that either temporal attention or visual grouping enhance temporal resolution, and that this effect is strongest when they are combined. Subsequently, the results obtained will be presented and discussed.

Chapter 3: Methods

3.1 Participants

Fifty participants took part in the experiment. All were university students between the ages of 18 and 50 years (M = 22.02 years). Forty-two participants were recruited via the Experiment Participation Pool of the Psychology Department. Eight participants were recruited via word of mouth. Forty-two participants were self-reported right-handers with an average EHI score of 92 (range: 40 to 100); eight participants were self-reported left-handers with an average EHI score of -36 (range: 50 to -100). Nineteen of the participants were male and 31 were female. All participants were compensated for their time either with course credits or money. The experiment was ethically approved by the University of Otago.

3.2 Apparatus

3.2.1 Computer and Mirror Box

The background stimuli were generated on an AMD Athlon™ 64 1.80 GHz personal computer with a NVIDIA GeForce FX 5200 graphics card, and presented on a 19-inch LCD monitor (Phillips 190C) at a resolution of 1280 ×1024 pixels and a frame rate of 75 Hz. The visual stimuli used for the measurements of temporal resolution were generated on a LabJack U3 (LabJack Corporation), and presented by two red LEDs.

A purpose-built wooden box was painted black to provide a black homogeneous background for the object-projections. The top of the mirror box was covered by a transparent plexiglass plate which served as a mounting for the LCD monitor and the LEDs. The LCD monitor was mounted on top of the plexiglass plate with its screen facing downward to a purpose built light-semipermeable mirror, which was fixed horizontally in the middle of the box, above the response board and under the plexiglass plate. Two small holes were bored into the plexiglass plate to adjust the LEDs below the LCD. Both LEDs faced the light-semipermeable mirror. Three lamps, consisting of 18 clear LEDs each, were fitted horizontally just above the response board and below the light-semipermeable mirror at the lower rear panel of the mirror box. The three lamps were covered by a transparent plexiglass plate and faced the response board. A wooden shade was fixed above the lamps to adjust the amount of light available, and to increase the semi-permeable light-effect. Two purpose-built armrests and a chinrest were placed in front of the mirror box. The apparatus as described above is shown in Figure 1.

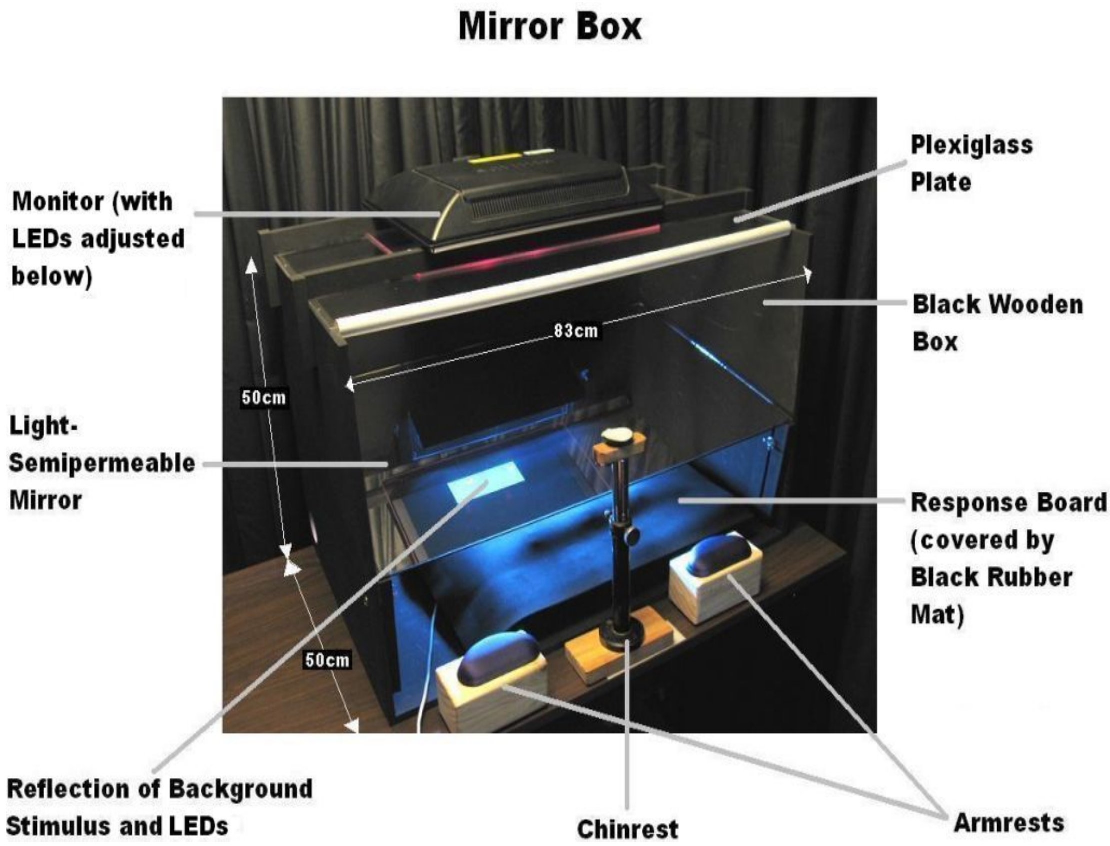

Figure 1.
The purpose-built mirror box. Subjects faced the light-semipermeable mirror. The stimuli were displayed by the monitor and the LEDs above the mirror. This setup generated an illusion of the stimuli appearing directly on the response board below the mirror.

This complicated apparatus was necessary because most monitors couldn't provide frame refresh rates which were fast enough to display the short stimulus onset asynchronies (SOAs) required for the purpose of the experiment. Moreover, a black homogeneous background which filled the whole visual field was provided by the mirror box and was necessary to ensure that no other objects could influence visual grouping or separation effects. Finally, the light-semipermeable mirror induced the illusion of touching the visually presented objects during task performance as shown in Figure 2. Thus, the effects of visual grouping and separation appear to be more realistic than if they were displayed on a normal computer screen.

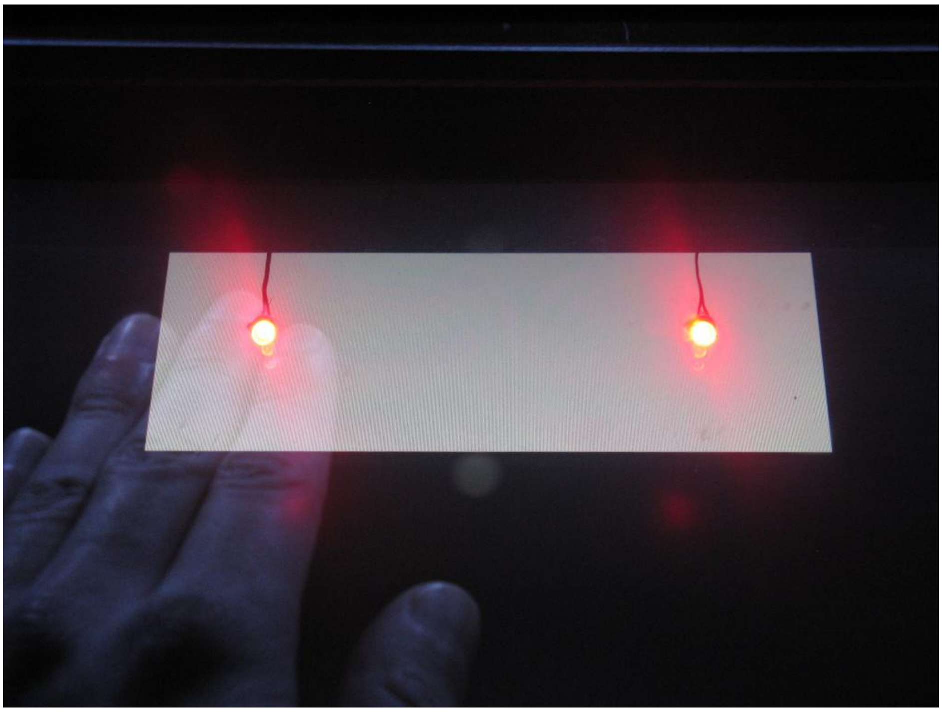

Figure2.
The illusion of touching the presented stimuli generated by the light-semipermeable mirror. Seeing the image of the wires leading to the LEDs was unavoidable. However, we suggest that it is highly unlikely that they influenced the desired visual effects

3.2.2 Response Board

A purpose-built wooden response board (see appendix A for a picture of the board) was connected to the LabJack U3, which in turn was connected to the desktop computer. The response board contained six press-buttons which were aligned in two rows. Four of the six buttons were used for the experiment as shown in Figure 3. A force of 7 N had to be applied to press the buttons, and they were unengaged by releasing them. The LabJack U3 transformed the analog input signals coming from the response board into digital signals, and transferred them via its output to the desktop computer. A black rubber mat covered the response board so it would blend in with the background of the mirror box. Therefore, the button locations were not visible, but detectable by touch.

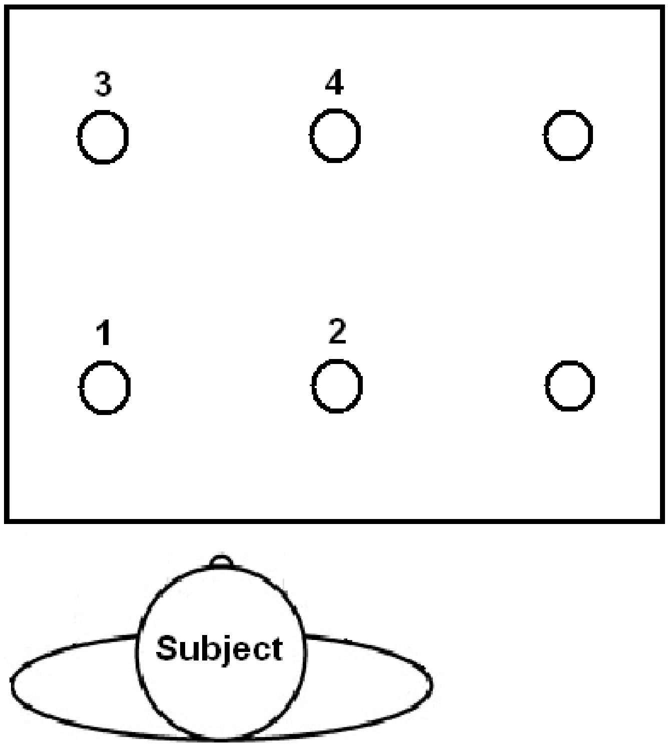

Figure 3.
Response board. Buttons 1 and 2 were used as home buttons; buttons 3 and 4 were used as target buttons. The remaining two buttons were not used. The response board was placed in the mirror box below the light-semipermeable mirror.

3.2.3 Data Acquisition and Control Device: Software-Hardware Interface

A LabJack U3 was used as an interface between the LEDs, the response board and the desktop computer. The LabJack device received commands from the MatLab software via a Universal Serial Bus (USB) connection, and transformed them into electric impulses to control the LEDs. At the same time it received analog signals from the response board and transformed them into digital signals, which in turn were transferred via the USB connection for data acquisition to the desktop computer. The LabJack U3 contained up to two counters, two timers, twenty digital inputs/outputs and up to sixteen 12-bit analog inputs.

3.2.4 Software

MatLab (MathWorks) editor version 7.1 (R14) was used to write the scripts which controlled the LEDs, the background objects, and to analyze the signals from the response board. Psychophysics Toolbox Version 2.54 (20 January 2004), an extended collection of MatLab functions, was used to execute precise timing commands (e.g. WaitSecs) or algorithms (e.g. QuestMean), which are essential in psychophysical experiments. MatLab was run in the No-Java mode to get the fastest signal processing times possible. Chart 5 (ADInstruments) was used to diagnose the voltage impulse recordings from the LEDs. SPSS 15.0 (LEAD Technologies) for Windows was used for the statistical analysis of the collected data.

The complete apparatus as described above is shown in Figure 4.

Figure 4.
Apparatus outside and inside the testing booth. All electronic equipment producing any kind of noise was placed outside the testing booth. The experimenter's workplace was set up in the booth because it was hoped that the subjects would feel observed and so would put more effort into their performance.

3.2.5 Apparatus- and Software-Setup: Pre-Experimental Development and Tests

LabJack U12 was used for pre-tests. To make sure that it received and transferred the MatLab commands with millisecond accuracy, an oscilloscope was connected to the LEDs to measure when exactly they flashed compared to the timing of the MatLab commands. A 16 ms time delay in signal processing was diagnosed which was too large for the purpose of the experiment, given that every millisecond more than about 5 ms is important for the measurement of the TOT. Moreover, LabJack U12 was not able to increase or decrease the timing commands received from MatLab with millisecond accuracy, but only in intervals of several milliseconds.

A quest for adequate equipment resulted in acquiring a LabJack U3 which was far superior to the U12 for our purposes. This time the direct impulse recordings from the LEDs were done with PowerLab/4SP (ADInstruments) and Chart 5 software, to ensure that LabJack U3 received the commands from MatLab and transferred them to the LEDs with millisecond accuracy. Figure 5 shows the PowerLab/4SP, which is connected via two channels with the LEDs of the mirror box.

Figure 5.
Two-channel voltage impulse recordings from two light-emitting diodes with PowerLab/4SP.

After the recordings, Chart data were compared with MatLab data. Figure 6 shows two-channel voltage impulse recording from the two LEDs of a 64-trial TOJ-task.

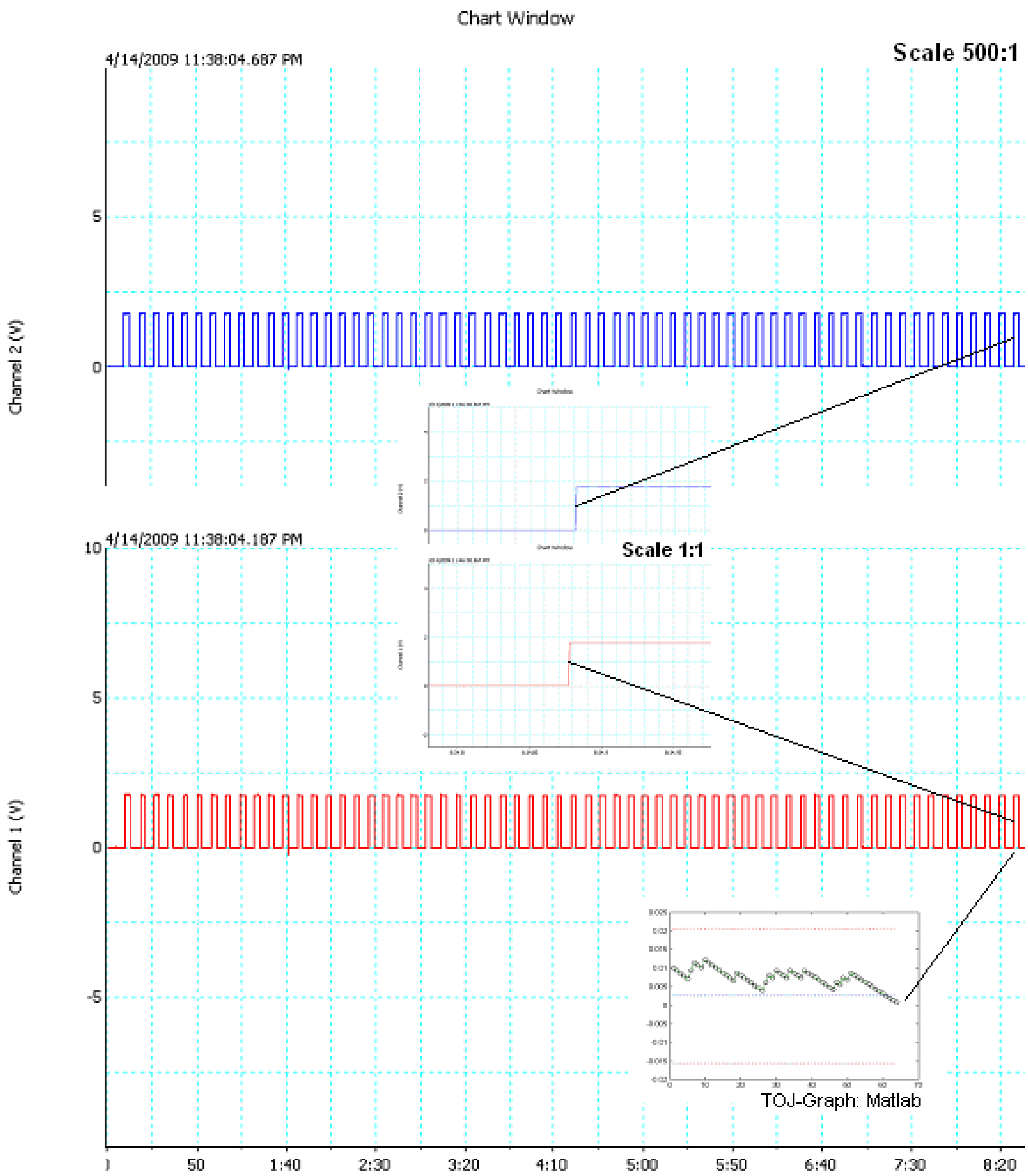

Figure 6.
Two-channel impulse recordings from two light-emitting diodes of a 64-trial TOJ task (details in text).

The x-axis in Figure 6 represents the time elapsed in minutes, seconds and tenths of a second and the y-axis represent the current flow of the LEDs in voltage, as obtained during recording. The inset graph in the middle of Figure 6 shows a scale-up of the last trial of the whole block run. The graph inset at the right bottom corner of

Figure 6 shows the course of the temporal order judgments during that block, recorded by MatLab. In Figure 7, the scale up of Figure 6 is shown.

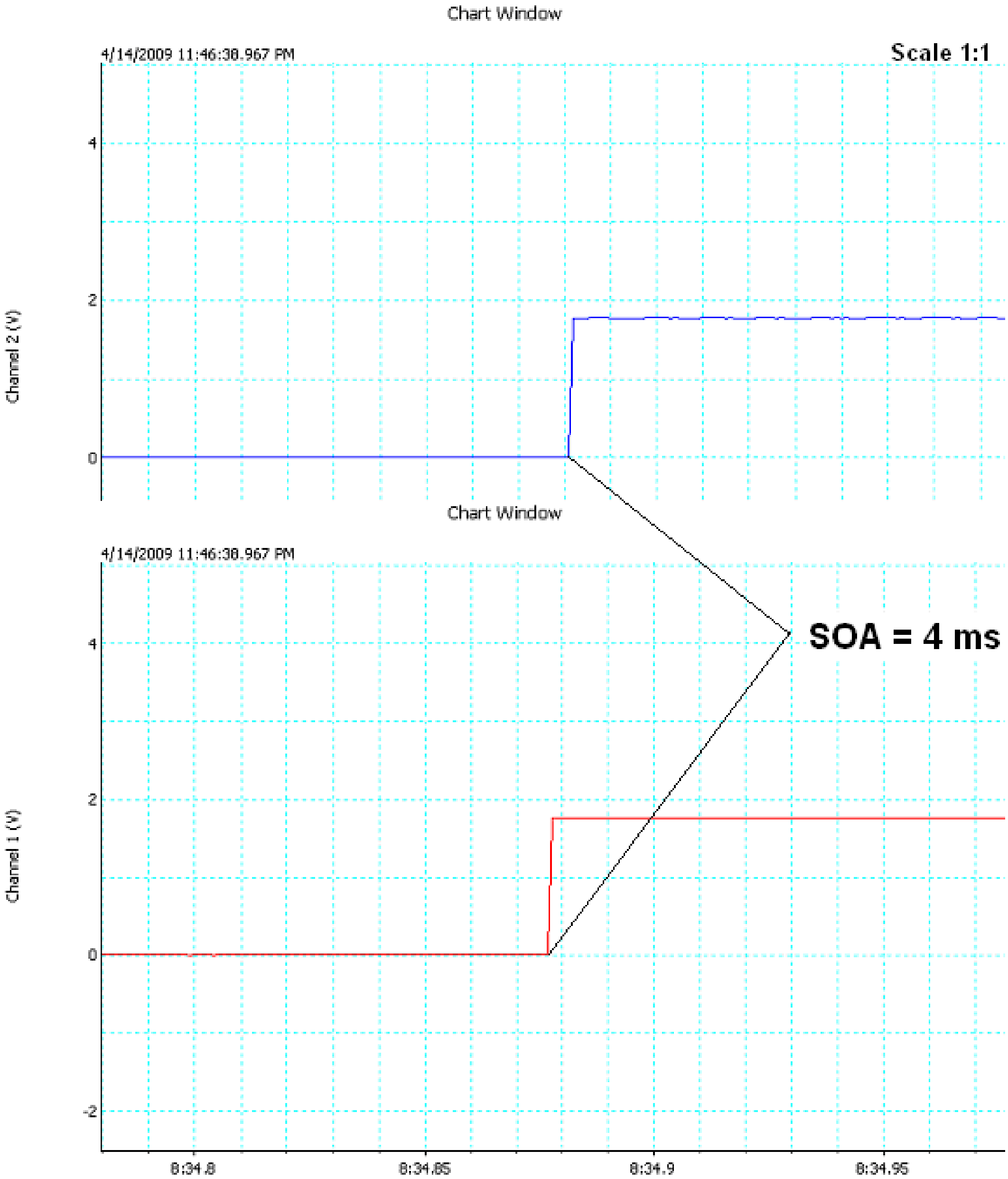

Figure 7.
Scale-up of a 4 ms stimulus onset asynchrony (SOA) is shown. It represents the shortest possible SOA given by the signal processing time limits of the equipment.

The x-axis in Figure 7 represents the time elapsed in minutes, seconds, tenths of a second, hundredths of a second, and milliseconds, and the y-axis represents the current flow at the LEDs in voltage. The resolution of Chart View was precise enough to display the shortest possible SOA with 4 ms in the graph.

It has been shown that MatLab data were consistent with the precise LED-impulse recording data of Chart indicating that LabJack U3 was able to control the LEDs exactly as desired for the experiment.

3.3 Stimuli

On each trial throughout all experimental conditions a fixation cross (0.2º × 0.2º visual angle (VA); thickness: 0.05º VA) appeared at the center of the screen between the LEDs. All stimuli were presented against a black homogeneous background which filled the participant's whole visual field. Stimulus presentation was controlled by MatLab, using the Psychophysics Toolbox extension (Brainard, 1997; Pelli, 1997). Measured to the reflection of the light-semipermeable mirror, the viewing distance to all stimuli was approximately 50 cm. Two LEDs were mounted in front of the LCD monitor at a 10.8º VA apart horizontally. The illuminance of each LED was 6 lm/m^2. The distance between each LED and the center of the screen was 5.4º VA. The timing of the LEDs was controlled by the QUEST algorithm (King-Smith et al., 1994), a function provided by the MatLab Psychophysics Toolbox. QUEST is an adaptive staircase procedure to measure psychometric thresholds. A detailed explanation about the QUEST procedure will be presented in the following chapter.

3.4 Experimental Conditions and Design

A 2 × 3 × 2 mixed-effects design was used, with the between-subjects factor Instruction (Wait, Standard) and within-subjects factors Stimulus type (Bar, Squares, Mixed) and Timing of the background (Abrupt, Persistent).

For each subject, a two-alternative forced choice (2AFC) paradigm was used with a defined stimulus intensity that generated a probably of 75% correct answers on the psychometric function. The interval between the LED-onsets, the so called stimulus-onset asynchrony (SOA), decreased if a correct answer for the temporal order of their appearances was given. Whenever the subject responded incorrectly, a reversal of order had occurred, hence the SOA increased. The threshold was calculated by QUEST for all experimental conditions in the following order: first, the mean of the stimulus values at the reversal points was calculated. Then a defined number of the first reversal points were discarded. Finally, the value in the stimulus vector that was nearest to the mean of the reversal points was calculated and returned.

There were three stimulus types in the experiment: Bar, Squares, and Mixed. For the Bar stimulus, a white bar with edge lengths of 18.2º VA (horizontally) × 6.5º VA (vertically) was displayed as a spatially-unified background stimulus to induce visual grouping of the two LEDs as shown in Figure 8. A bar was also used in an earlier study for visual grouping of two spatially separated objects (Xu & Chun, 2007).

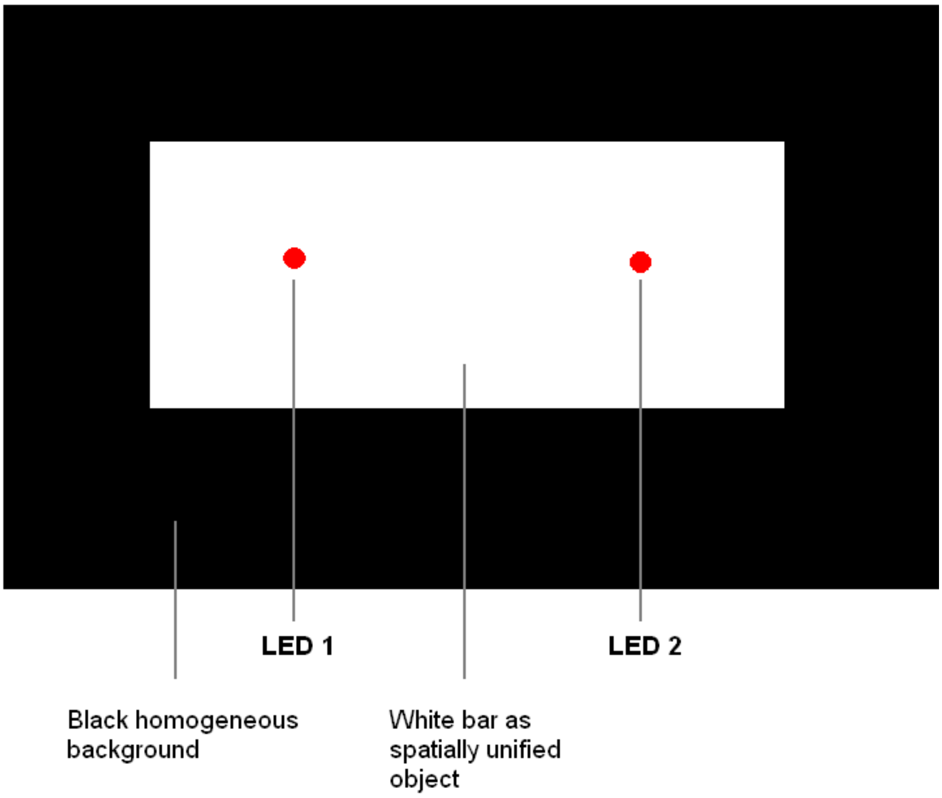

Figure 8.
Bar Stimulus: Two LEDs lit up against a white bar which was used as a spatially unified background object to induce visual grouping of the LEDs.

For the Squares stimulus, two white squares, each with an edge length of 6.5º VA were displayed 4.3º VA horizontally apart as spatially non-unified background stimuli for the LEDs, and comprised a control condition for the unified one as described above. This type of stimulus was used to spatially separate the LEDs as in Figure 9.

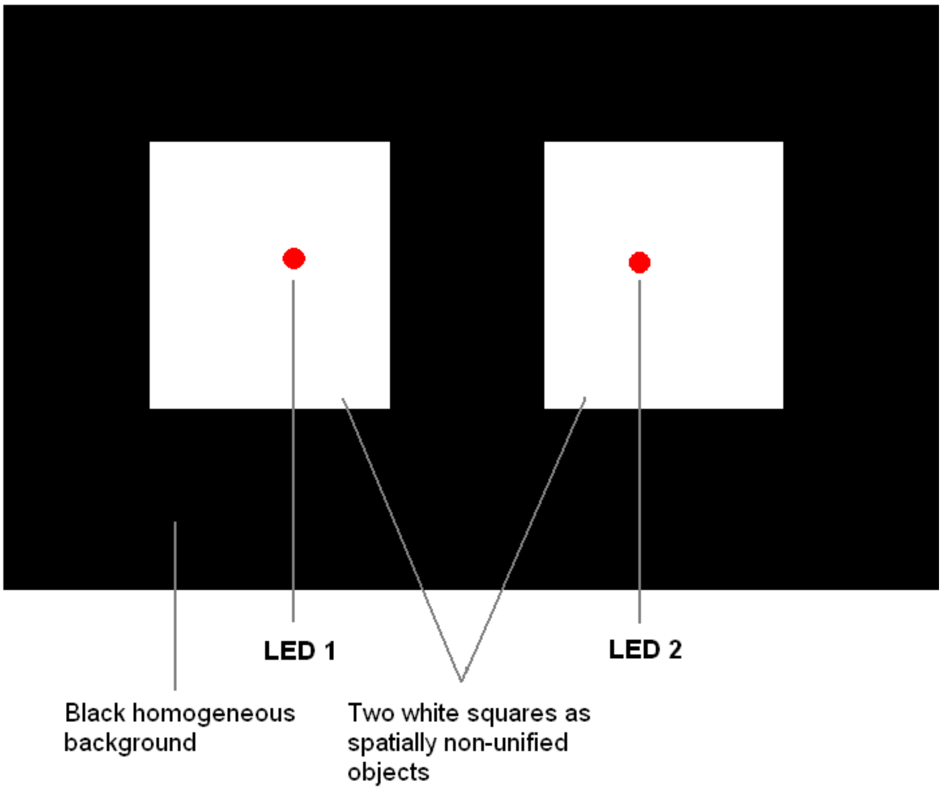

Figure 9.
Squares Stimuli: Two LEDs lit up against two white squares which were used as spatially-non-unified background objects to visually separate the LEDs.

For the Mixed stimulus, Bar and Squares stimulus types were displayed in alternation. All types of stimuli were crossed with two types of timing of the background (Abrupt and Persistent). These were within-subjects factors.

The between-subjects factors were two types of instructions. Subjects in one group were asked to be certain of which LED appeared first before making any judgments on temporal order (Wait instructions). Subjects in the other group were instructed to perform the task without such deliberation, as quickly and automatically as they could by allocating their attention more on the first flash (Standard instructions). These manipulations were used to assess whether some early information processing associated with TOJs might result in different effects on TOTs than judgments based on certainty about temporal order.

All participants performed 7 blocks with 50 trials in each. The timing of the trials was controlled using MatLab Psychophysics Toolbox. The first block performed by all participants contained the neutral stimulus condition. No background stimuli were displayed in the Neutral condition as shown in Figure 10. It served as a rough TOT estimation for the following blocks, and was therefore excluded from the data analysis. The TOT outcome of the first block was used as a guess value in the QuestMean algorithm which controlled the LEDs in the remaining six blocks of different background and stimulus conditions which were performed in randomized order. This method was suggested by Pelli and Farell (Farell & Pelli, 1999; Pelli & Farell, 1995) to provide a confidence interval for a guess as to where the threshold may lie. A response criterion of 75% correct responses was used for TOT estimation.

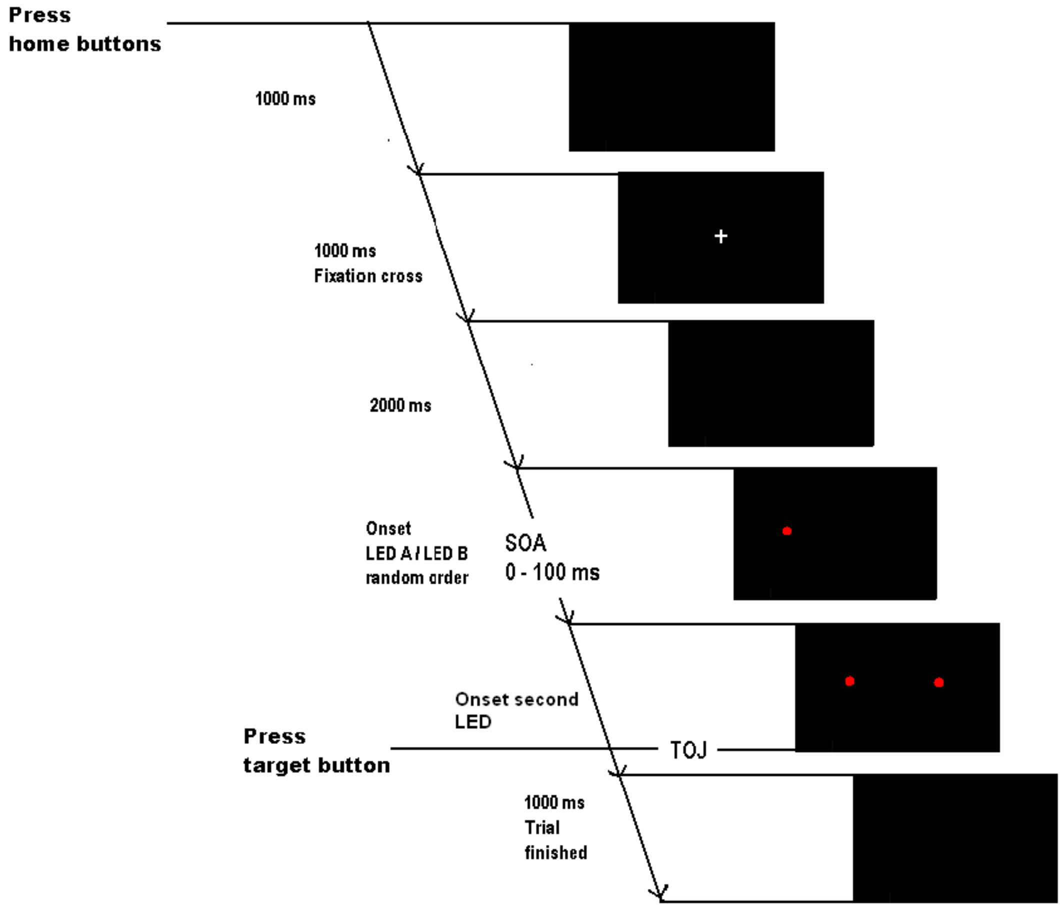

Figure 10.
Trial sequence of Neutral condition. No background stimuli were displayed.

The bar stimulus was used as background object for the LEDs in the Bar Abrupt condition throughout the whole block. The bar appeared with constant foreperiods of 1000 ms before the onsets of the first LED as shown in Figure 11.

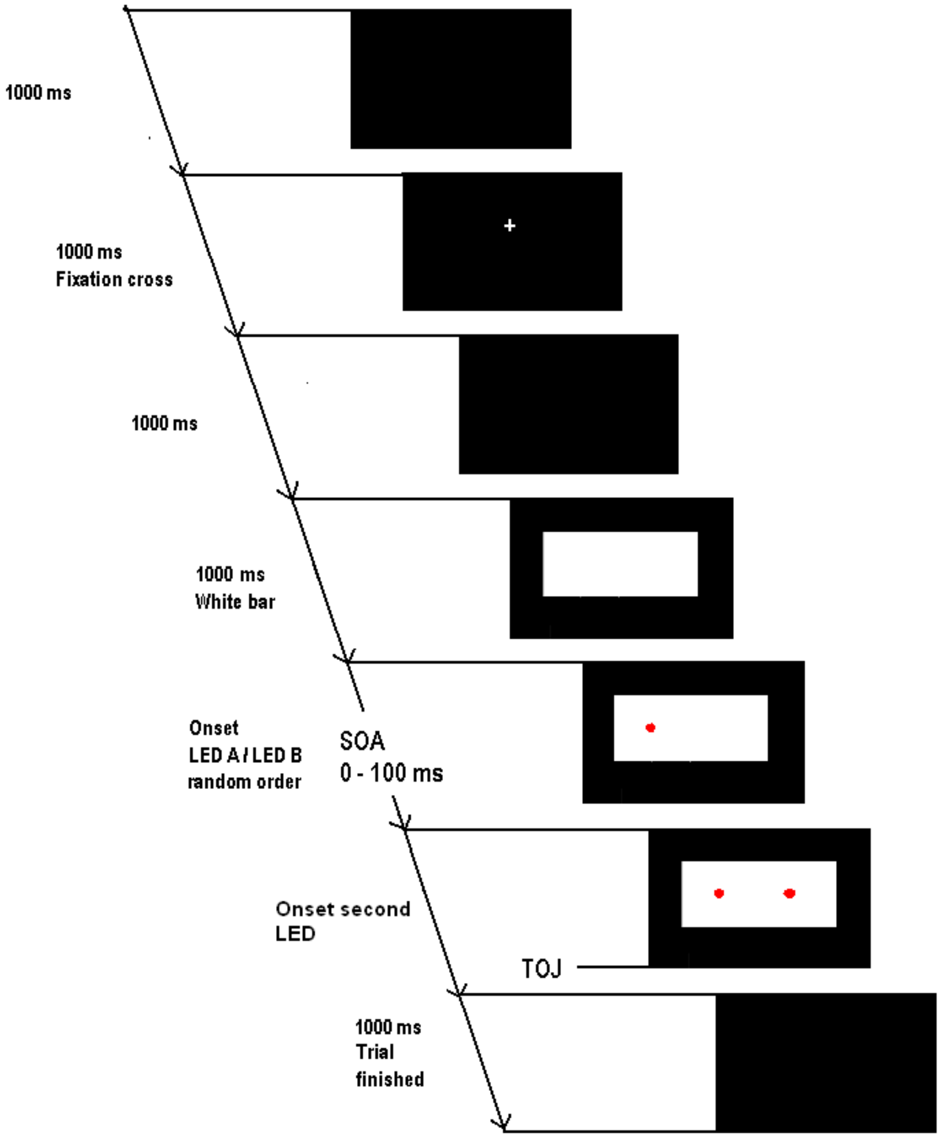

Figure 11. Trial sequence of Bar Abrupt condition. The bar stimulus appeared 1000 ms before the onset of the first LED.

The bar stimulus was used as a background object for the LEDs in the Bar Persistent condition throughout the whole block. It was displayed persistently in each trial as shown in Figure 12.

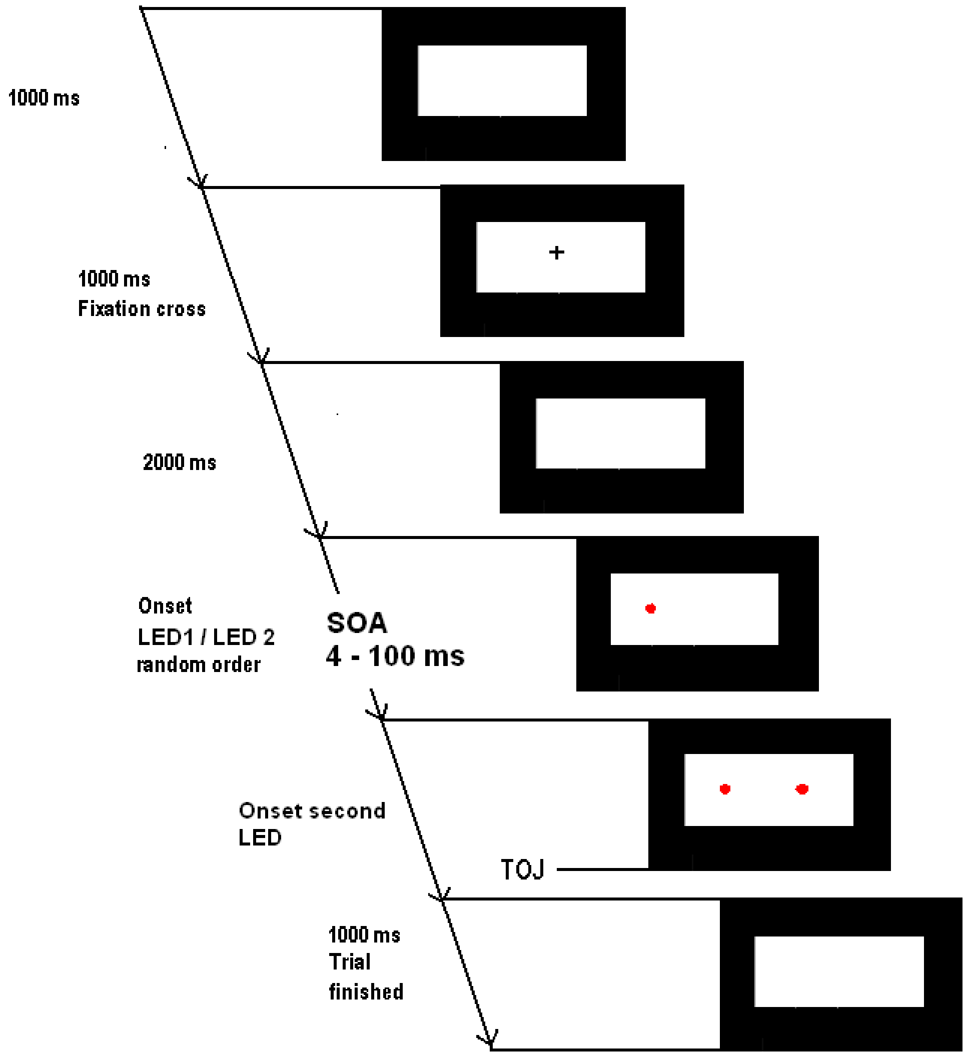

Figure 12.
Trial sequence of Bar Persistent condition. The bar stimulus was displayed persistently during the whole trial.

The squares stimuli were used as background objects for the LEDs in the Squares Abrupt condition throughout the whole block. The squares appeared with constant foreperiods of 1000 ms before the onsets of the first LED as shown in Figure 13.

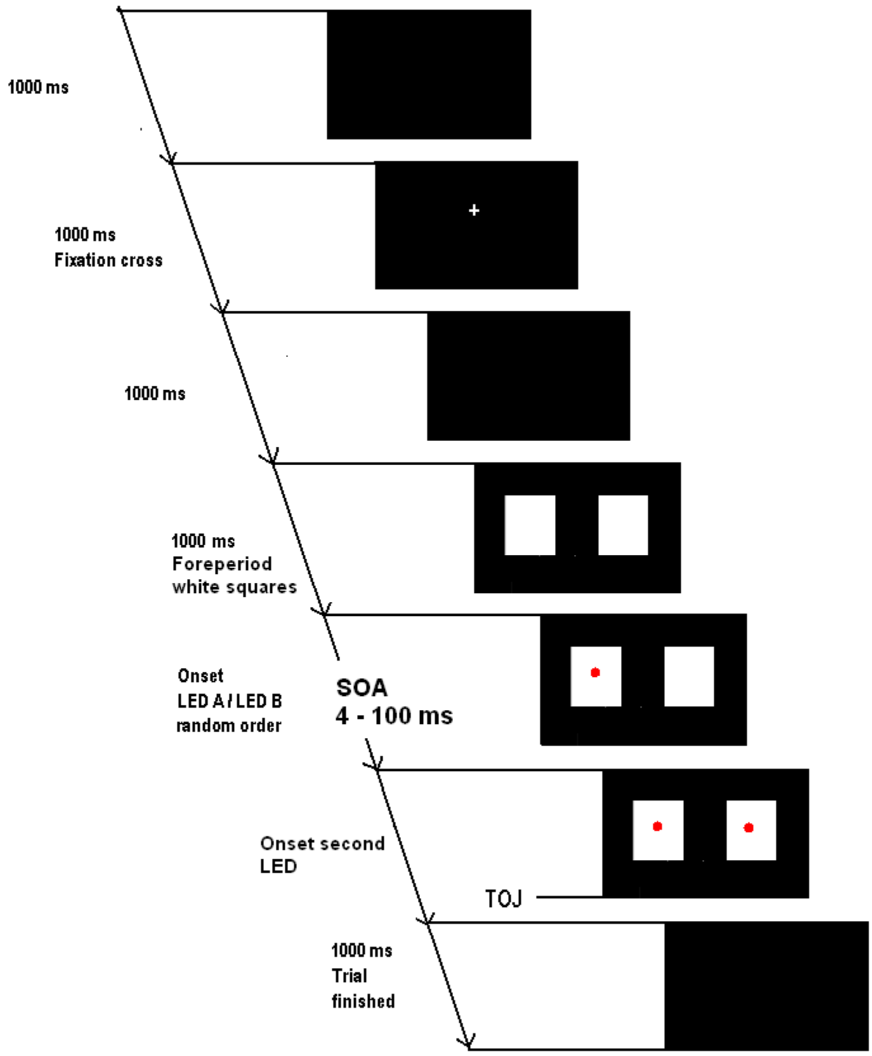

Figure 13.
Trial sequence of Squares Abrupt condition. The squares stimuli appeared 1000 ms before the onset of the first LED.

The squares stimuli were used as background objects for the LEDs in the Squares Persistent condition throughout the whole block. They were displayed persistently in each trial as shown in Figure 14.

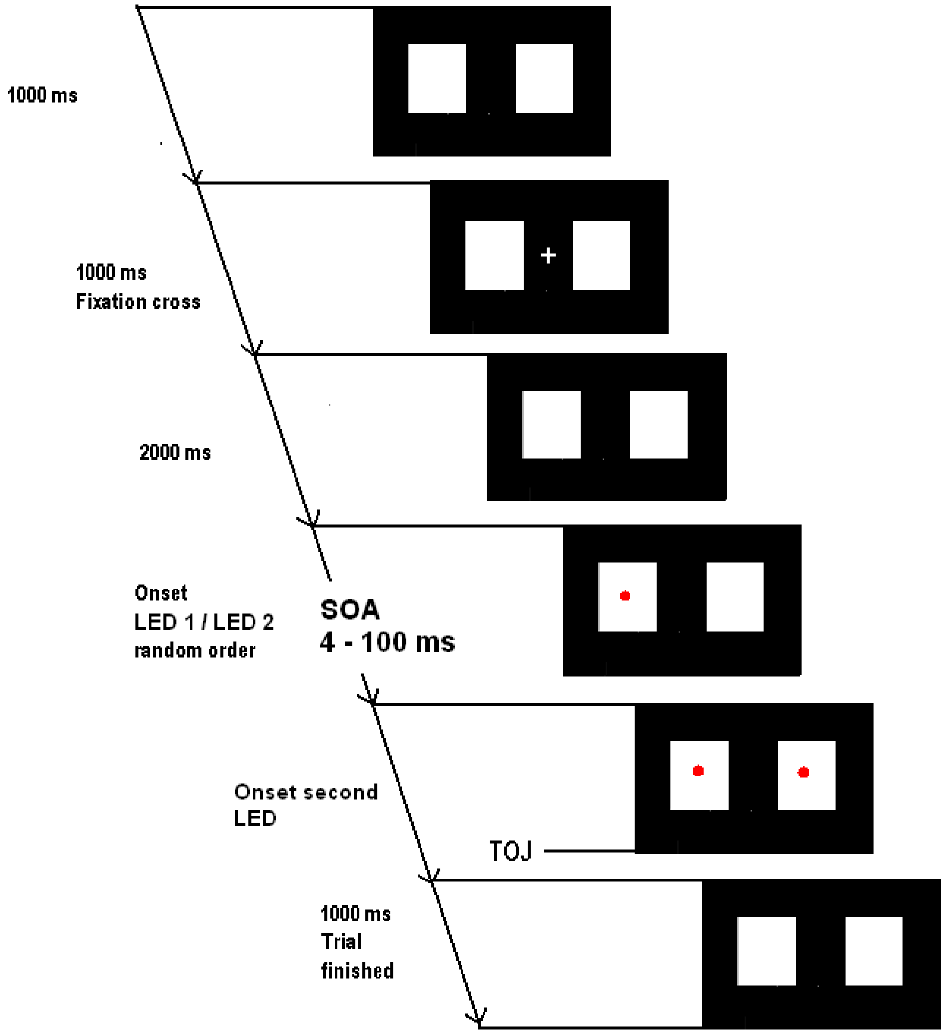

Figure 14.
Trial sequence of Squares Persistent condition. The squares stimuli were displayed persistently during the whole trial.

In the Mixed Abrupt condition, Bar Abrupt, and Squares Abrupt conditions were displayed in alternation throughout the whole block as shown in Figure 15. This design was used to test possible differences associated with switching between the two stimuli compared to the blocked fashion as used in the above conditions.

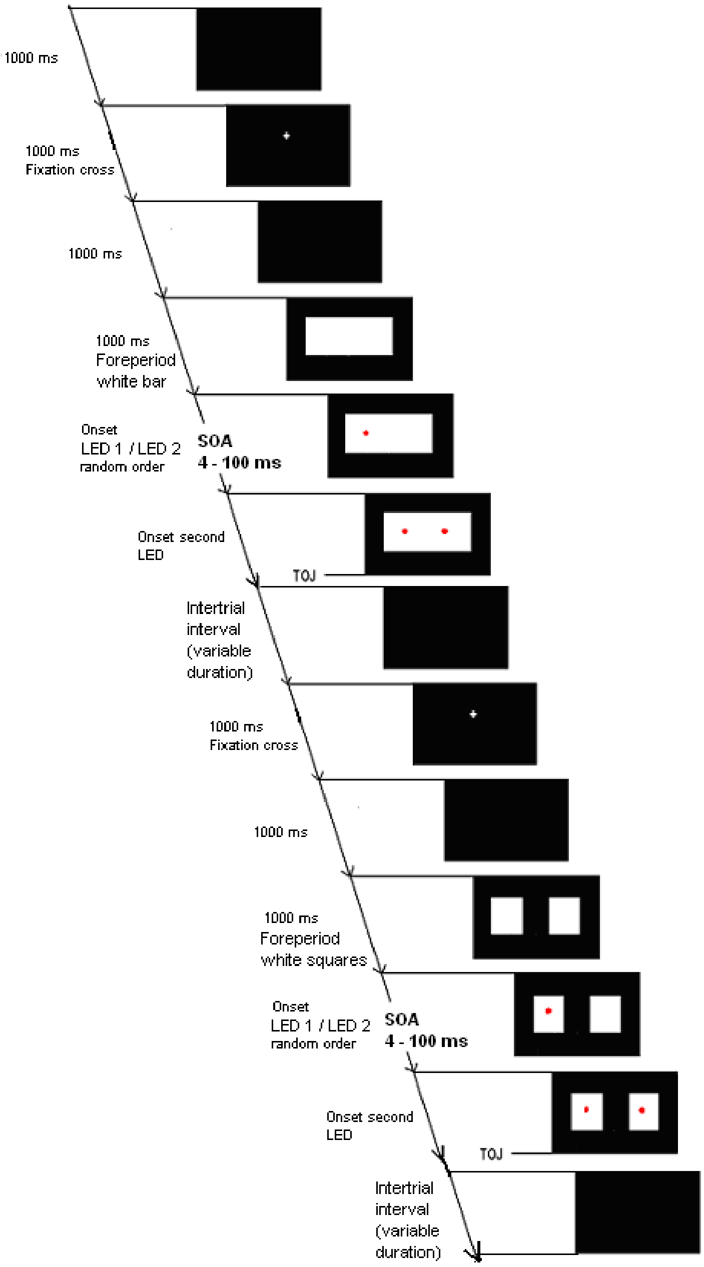

Figure 15.
Trial sequence of Mixed Abrupt condition. Bar and squares stimuli appeared abruptly in alternation throughout the whole block.

In the Mixed Persistent condition, the Bar Persistent and Squares Persistent conditions were displayed in alternation throughout the whole block as shown in Figure 16. This design was applied to test possible differences between mixed and blocked fashion of stimulus presentation as described in the previous section.

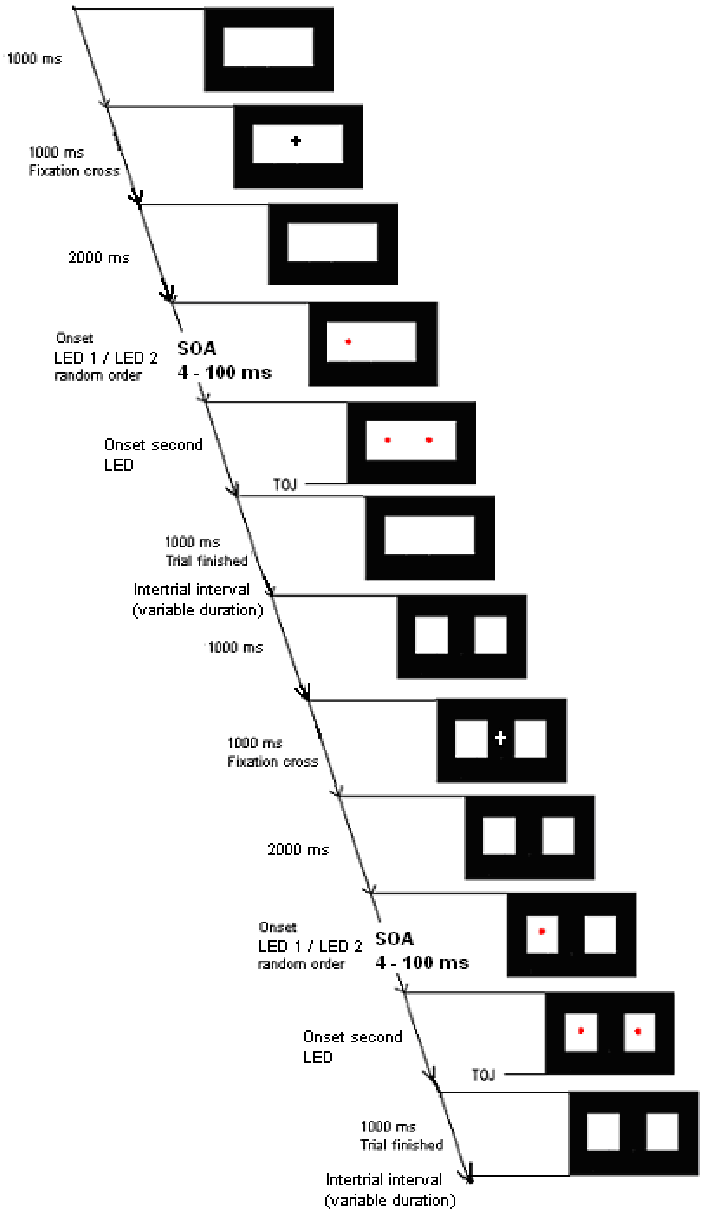

Figure 16.
Trial sequence of Mixed Persistent condition. Bar and squares stimuli appeared persistently in alternation throughout the whole block.

3.5 Procedure

The standard procedure for all stimulus conditions is shown in Figure 10. Both home buttons were pressed to start each trial. After 1000 ms, a fixation cross appeared at the center of the screen. It remained for 1000 ms. Then, after another 2000 ms the first LED appeared with equal likelihood on the left side or on the right side of the center of the screen. After a variable SOA of 4 to 100 ms, the second LED lit up on the opposite side of the centre of the screen. Both LEDs remained on until the participant finished his or her TOJ by pressing a target button. The next trial was started after the participant moved his or her hands from the target button back to the home button. The detailed time courses of the trial sequence conditions used in the different blocks are described in the following sections.

Before every experimental session, the participants were asked to read the *Information Sheet for Participants* (see appendix B) which contained all information and safety instructions concerning the experiment. If the participants agreed, they were asked to read and sign the *Participation Consent Form* (see appendix C). After a short explanation about some methodological aspects of the experiment, the participants were shown into the booth which contained the experimental setup. Further demographics were collected before they were asked to take a seat on a swivel chair in front of the mirror box and place their chin on the chinrest so that the reflection of the two LEDs in the mirror box would be clearly seen. Once the swivel chair was adjusted into a suitable position, a short practice run of five to ten trials began. The following standard explanation protocol was used in every experimental session:

1. The subject was asked to put his/her forearms on the armrests and his/her hands on the two home buttons (left hand on the left home button and right hand on the right home button) of the reaching board (see Figure 3) below the light-semipermeable mirror.
2. Given that the response board was covered by a black rubber mat, the areas of the buttons were not visible, but detectable by the hands. Thus, the subject's hands were guided to the locations of the buttons.
3. The subject was told that two more buttons (target buttons) were located exactly at the location of the two LED reflections near the back end of the mirror box.
4. The subject was asked to keep pressing down the two home buttons and to keep his/her eyes on the fixation cross between the two LEDs.
5. The script which controlled the LEDs and the background stimulus conditions was started.
6. The subject was asked to judge which LED appeared first and to move his/her left hand to the left target button if the left LED appeared first, and his/her right hand to the right target button if the right LED appeared first. After pressing either the left or the right target button once (depending on which LED was judged to have lit up first), the subject was asked to bring his/her responding hand back to the home button to press it down again, while the other home button was to be pressed down during the whole trial.
7. The subject received either the Wait instruction or the Standard instruction as explained in Chapter 3.4 Experimental Conditions and Design.
8. The subject practiced for some trials with the neutral stimulus condition to make sure that he/she fully understood the task.

9. Each subject was told that a query after each block of trials would probe difficulty, using a *Level of Difficulty Form* (see appendix D) using a scale from 1 to 10. They would also be asked if any apparent motion (AM) illusion was experienced between the two LEDs, and approximately how many times out of the 50 trials a guess was made.
10. The subject was asked to keep the same level of concentration for all blocks of trials. Subjects were also informed that two longer breaks would be taken, one after block 3 and one after block 5, while shorter breaks would be taken after the other blocks.
11. After the final instructions were given to a subject, all lights in the booth were switched off and the door was closed to avoid any visual or auditory distraction.
12. The main experiment was then started.

3.6 Data Collection

All data were collected in a sound-attenuated and electrically shielded booth which contained a mirror box with an integrated response board and a mounted LCD monitor. A separate experimenter's LCD monitor plus keyboard were connected to a desktop computer outside the booth for data collection and recording. Safety instructions or precautions were not necessary, since none of the subjects was connected to any kind of electrical equipment. An *Edinburgh Handedness Inventory Form* (see appendix E) was given to every participant before the start of the experiment.

The analog button press signals from the response board were received by the LabJackU3 data acquisition device, which in turn transformed them into MatLab-compatible digital data. The LabJackU3 transferred these signals via USB connection to the desktop computer. Data were recorded by MatLab and saved after each block as files in .mat-format. TOT outcome values were ordered within a 1×50 array for analysis. MatLab Psychophysics Toolbox was running in the no-Java mode to get the fastest signal processing time possible.

3.7 Statistical Analysis

A mixed-effects Analysis of Variance with repeated measures was used for all tests with a 2 × 3 × 2 factorial design. The between-subjects factors were instruction group (Wait instruction versus Standard instruction). The within-subjects factors were stimulus type (Bar versus Squares versus Mixed) and background type (Abrupt versus Persistent). T-tests were conducted for pairwise comparisons to determine the individual effects of the different background stimulus conditions on TOJ. Alpha was set at .05 for all analyses. All t-tests and F-tests were two-tailed.

In the following chapter, examples of qualitative plots of the data will be presented to demonstrate some prototypical patterns of responding. Subsequent to the qualitative analysis, the significant effects and meaningful trends from the statistical analysis will be reported.

Chapter 4: Results

4.1 Temporal Order Threshold Plots and Qualitative Analysis

Given that concentration in experimental performance fluctuated more or less within and throughout the different block conditions, it was important to test a large number of subjects on the task to see the more consistent patterns across them. However, as the graphs suggest, most subjects performed according to their best physical and psychological capacities, at least insofar as we can infer from the data. For example, as shown in Figure 17, there were subjects who demonstrated patterns of data that were completely in line with expectations. From Figure 17, one can clearly see the staircase procedure working across trials.

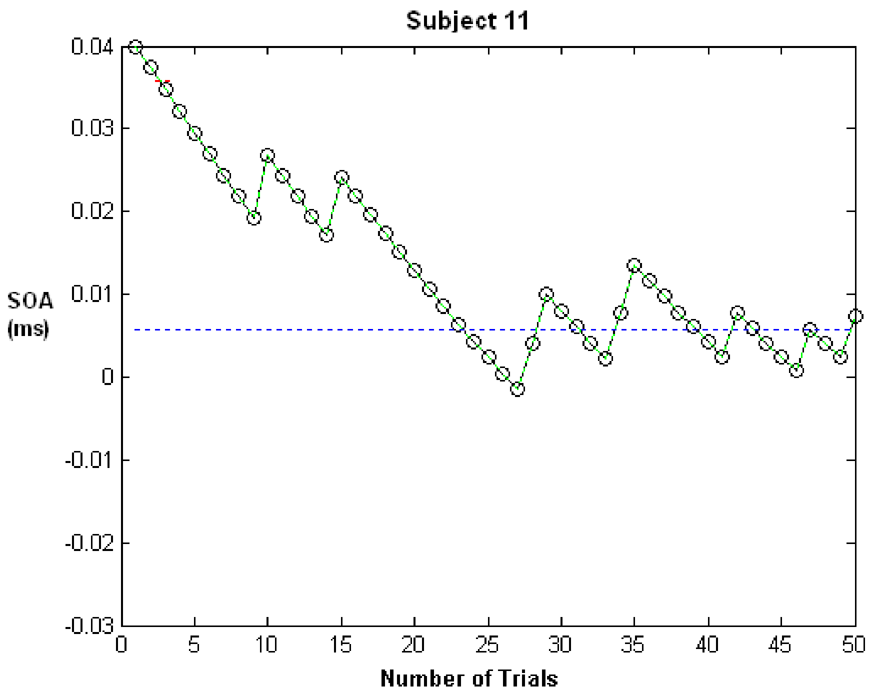

Figure 17.
An example of a subject's ideal performance in TOJ. The blue dashed line represents the TOT, which is calculated by the QuestMean algorithm (details in text).

Each dot in Figure17 represents one trial. The block started with an SOA of 40 ms. Every time the subject responded correctly, the SOA became shorter, while wrong responses prolonged it according to the QuestMean algorithm. The graph clearly shows how the dots start to fluctuate around an imaginary line. This line is also calculated by QuestMean, and represents the subject's TOT. Interestingly, subject 11 showed an unusually low TOT of 10ms. Note, as mentioned in Chapter 3 Methods, a 4 ms signal processing delay must be added to the values which are represented by the dots in Figure 17 and 18. However, it is important to mention that such low TOTs are absolutely realistic, even in the visual domain. Subjects with broader fluctuations of concentration can also show very realistic TOTs (Figure 18).

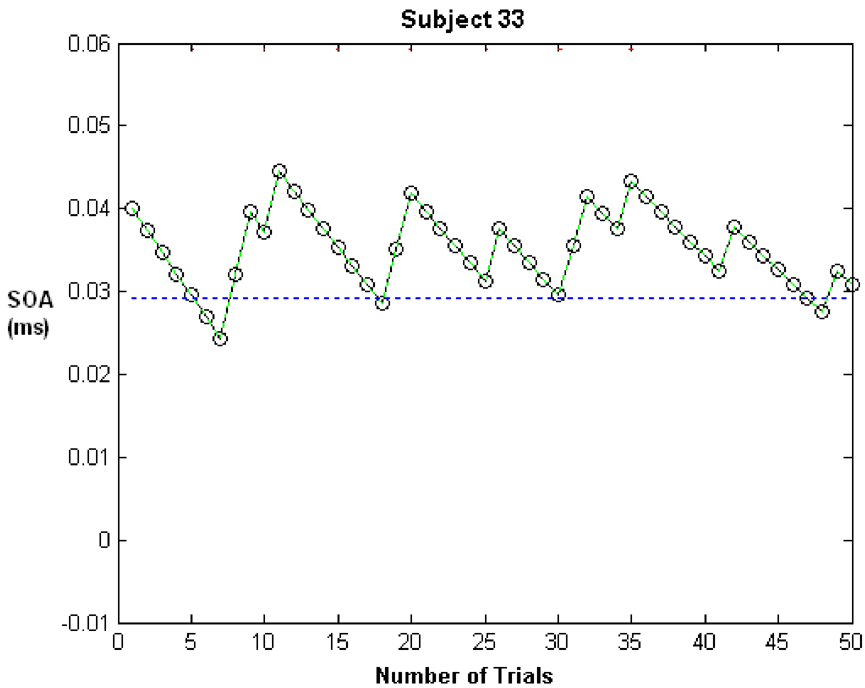

Figure 18.
An example of a subject's performance in TOJ with what we interpret as being likely due to broader fluctuations of concentration. The blue dashed line represents the TOT, which is calculated by the QuestMean algorithm.

4.2 Statistical Results on Background Type and Stimulus Type

The effect of background type in Abrupt versus Persistent stimulus conditions was highly significant, $F(1,48) = 8.047$, $p = .007$. The TOTs were notably lower when abrupt background stimuli were displayed (Figure 19).

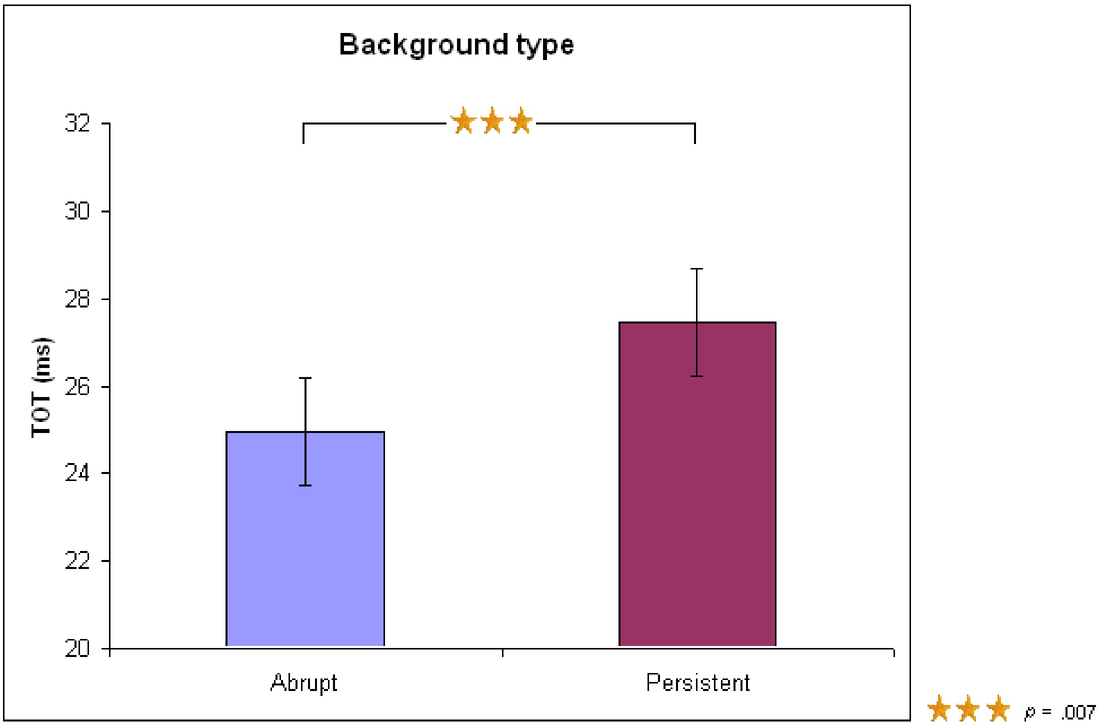

Figure 19.
TOT means for Abrupt and Persistent stimulus presentation. TOTs in Abrupt stimulus conditions are clearly lower than in Persistent stimulus conditions. Error bars represent standard error of the mean.

The effect of the background type was not significant for the two groups that differed on the basis of the instructions they received, $F(1,48) = 0.360$, $p = .551$.

Pairwise comparisons for blocked (non-Mixed) conditions revealed a significant effect for Bar versus Squares stimulus conditions, $F(1,48) = 5.230$, $p =$

.028. The TOTs were clearly lower when a bar was displayed as the background stimulus (Figure 20).

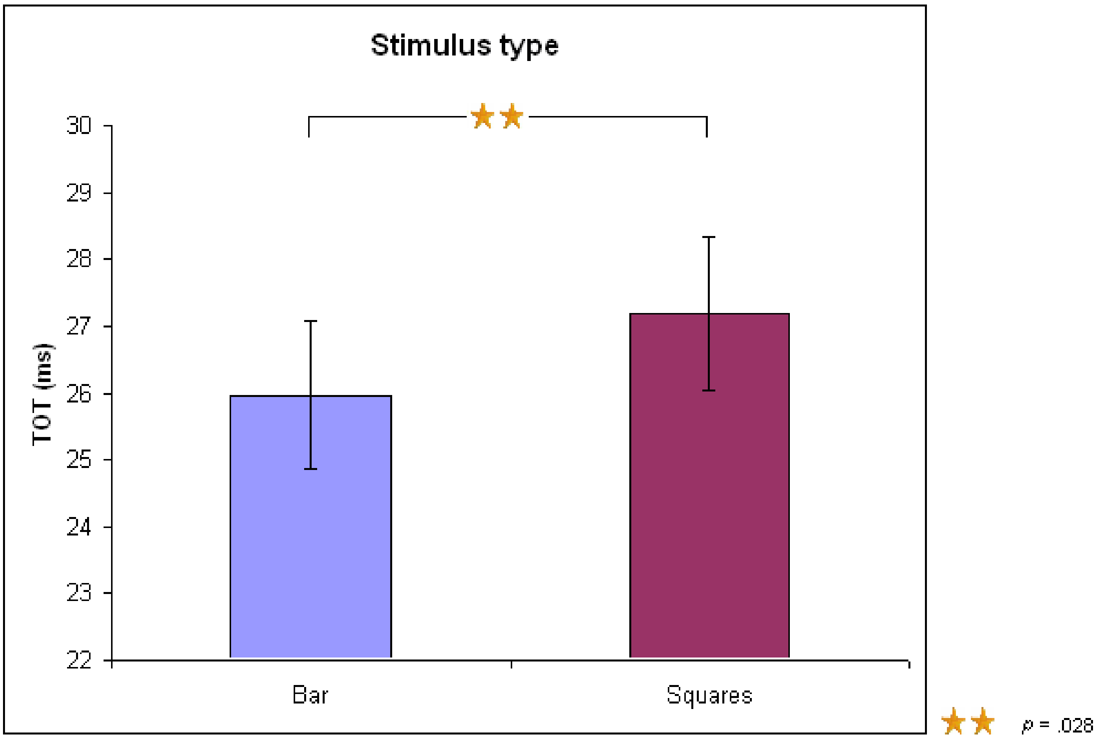

Figure 20.
TOT means for Bar and Squares stimulus conditions. TOTs in Bar stimulus conditions were significantly lower then in Squares stimulus conditions. Error bars represent standard error of the mean.

The effect of the stimulus type was not statistically significant in the Mixed conditions, $F(1,49) = 0.484$, $p = .490$. The interaction between background type, stimulus type and the two groups (with different instructions) was not statistically significant, $F(2, 96) = 1.707$, $p = .187$.

Post hoc paired-samples t-tests were conducted for stimulus conditions Bar Abrupt, Squares Abrupt, Bar Persistent and Squares Persistent to clarify the two main effects reported above. From the earlier analyses, we would predict that the Bar

Abrupt stimulus condition should lead to significantly lower TOTs than the Squares Persistent stimulus condition because of the combined effect of Abrupt background and Bar stimulus.

The effect of background type and stimulus type was highly significant for the comparison of Bar Abrupt and Squares Persistent stimulus conditions, $t(49) = 2.997$, $p = .004$. The TOTs in the Bar Abrupt condition were significantly lower than in the Squares Persistent condition (Figure 21). Moreover, a significant effect of background type was found for the conditions Squares Abrupt and Squares Persistent, $t(49) = 2.080$, $p = .043$. The TOTs were significantly lower in the Squares Abrupt condition than in the Squares Persistent condition (Figure 21). A marginally significant effect was found for the comparison of Bar Abrupt and Bar Persistent, $t(49) = 1.725$, $p = .091$. TOTs in the Bar Abrupt condition were lower than in the Bar Persistent condition (Figure 21). There was no significant effect for the stimulus conditions Squares Abrupt and Bar Persistent, $t(49) = 1.223$, $p = .227$.

In sum, performance in TOJ was enhanced in conditions with Abrupt backgrounds and Bar stimuli, and best when both factors were combined. The results of the post hoc pairwise comparisons qualify the particular findings of the previous omnibus tests.

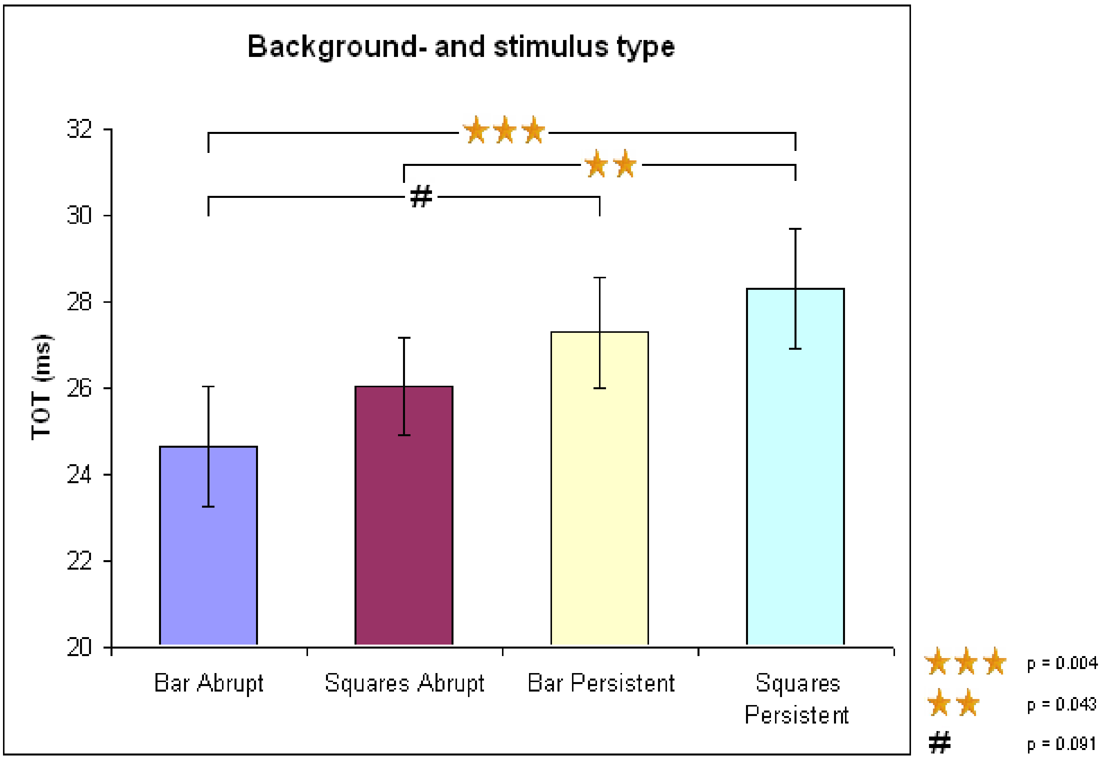

Figure 21.
TOT means for all stimulus conditions (except for Mixed conditions). TOTs in the Bar Abrupt condition were significantly lower than in the Squares Persistent condition. TOTs in Abrupt conditions were lower than in Persistent conditions. Error bars represent standard error of the mean.

Chapter 5: Discussion

5.1 Summary of Results

The primary purpose of this study was to develop and apply an experimental design to investigate the influence of visual grouping and temporal attention on temporal resolution using a TOJ paradigm. Thus, it was our aim to understand the processes involved in TSE. A secondary aim was to include different subject instructions to assess the influence of early and late information processing in TOJ.

The literature discussed in Chapter 2 points out that there is disagreement as to whether visual grouping facilitates temporal resolution or not. Testing these contradictory findings, a clear experimental design with straightforward stimulus types was applied. This was accomplished by using a bar stimulus as a visually unified background object for the purpose of visually grouping two LEDs. A bar stimulus was also used in previous research for visual grouping of distinct objects (Xu & Chun, 2007). In the control condition, two squares, one forming the background of each separate LED, were used as visually non-unified background objects for visual separation. Temporal resolution in the different stimulus type conditions was determined by applying the scientifically established TOJ paradigm consisting of judgments of the temporal order of LED-onsets. Results obtained in the experiment conducted on 50 participants have shown that TOTs were significantly lower when the visually unified background stimulus was displayed, compared to non-unified stimuli. Thus, the first hypothesis of this study is verified. The results are in line with the studies presented in Chapter 2 showing that visual grouping facilitates temporal resolution (Vidal et al., 2006; Xu & Chun, 2007). No statistically significant effects of the stimulus type could be found in the mixed conditions in which the two types of background stimuli were alternated within a block of trials. Thus, we assume that switching between the two stimulus types washes out the grouping effects that occur in completely a blocked fashion.

It can be gathered from the literature in Chapter 2 that there is a body of evidence that temporal attention tends to enhance temporal resolution. Testing this finding, in the present experiment the subjects' attention to temporal properties of the background stimuli was induced by using abrupt stimuli which appeared with a specific temporal interval prior to the onset of either LED. This kind of design with constant foreperiods was applied in previous research to influence subjects' temporal attention (Bausenhart et al*.,* 2008). Results obtained from this experimental manipulation have shown that TOTs were significantly lower when the background stimuli were displayed abruptly compared to persistently. Given that, the second hypothesis of this study is verified. The results are in line with previous research showing that temporal attention can improve temporal resolution (Bausenhart et al., 2008; Correa et al., 2006).

To our knowledge, this is the first study to investigate the combined influences of both visual grouping and temporal attention on temporal resolution. Taking advantage of this, all stimulus-types were crossed in all possible combinations providing a novel experimental design. As expected, TOTs were lowest when both of the above factors were combined and highest when both were absent. Thus, the third hypothesis of this experiment is verified. This novel finding indicates that temporal resolution is higher when both visual grouping and temporal attention are present in combination compared to when either is present individually.

A final aim of the experiment was to assess whether early information processing in TOJ results in different effects on TOTs than late information processing. Testing this experimental question, participants were assigned to two groups receiving different instructions. Participants in one group were asked to perform their TOJs as soon as they saw the first flash. Participants in the other group were instructed to be certain before indicating their TOJs by responding. However, no significant effects of this manipulation could be found, suggesting that participants of both groups used similar cognitive strategies for their TOJs despite the different instructions. It is possible, however, that this manipulation was not sensitive to differences in early or late information processing.

Taken together, all hypotheses of this study presented in Chapter 1 were verified successfully. Moreover, the verification of the third hypothesis of this study is a new scientific finding revealing novel information about the influence of both visual grouping and temporal attention on temporal resolution. The results of our study provide evidence that multiple processes are involved leading to increased temporal resolution during TSE.

5.2 Discussion of Findings of this Study in the Context of Previous Research

In contrast to the results of our study, Nicol and Shore (2007) found that perceptual grouping impairs temporal resolution. We suggest that their results differ from ours because they applied another method of visual grouping. We used separate spatially unified or non-unified background stimuli for grouping or separating two distinct target objects (LEDs) for which temporal order of appearance judgments were performed, whereas Nicol and Shore (2007) merely used the same stimuli for the purpose of grouping or separating their displays and also to display onsets for temporal discrimination as shown in Figure 22.

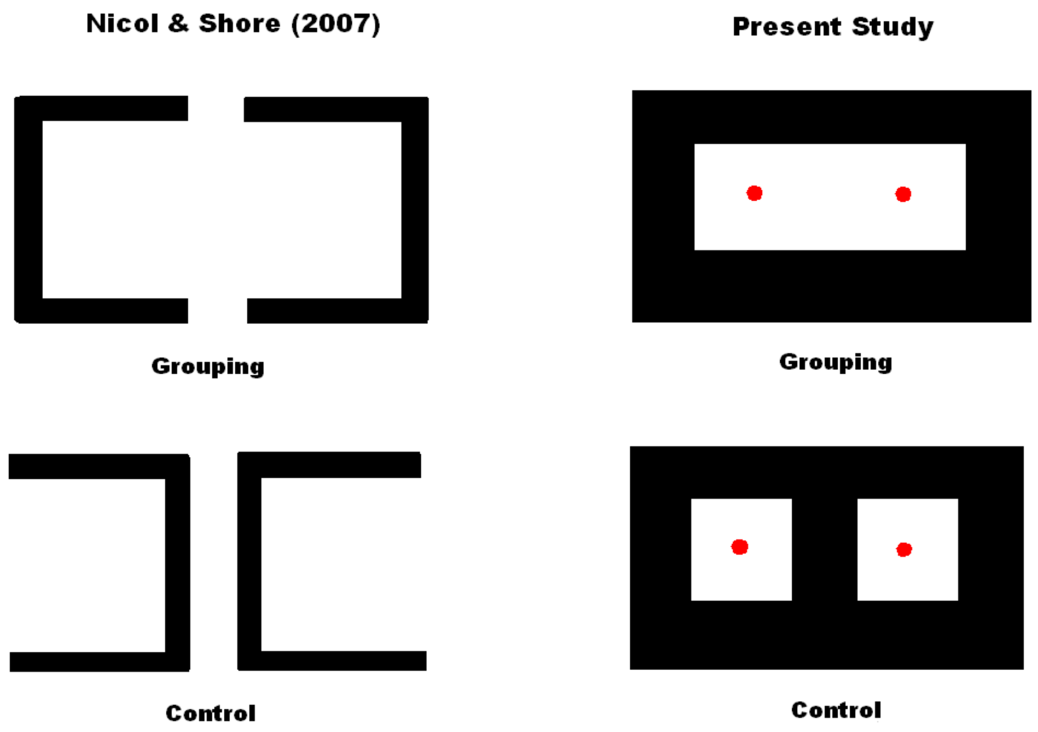

Figure 22.
On the left: Target stimuli used in Nicol and Shore (2007) for grouping and control condition. Stimuli appeared with defined SOAs between them. On the right: Target stimuli represented by two LEDs used in the present study. Stimuli appeared with defined SOAs between them. Additional stimuli were used for visual grouping and separation.

Examining Figure 22, the reader can imagine how visual grouping can affect discrimination between distinct objects in different ways. It appears to be more difficult to discriminate between the onsets of the target stimuli that Nicol and Shore (2007) used in their study for grouping compared to those they used in the control condition because the grouped stimuli in their study can be considered as one object while the stimuli they used in the control condition are easily distinguishable as two objects. In the present study the distinct target stimuli were grouped by using a bar as an additional stimulus while squares were used in the control condition. We suggest that it is easier to focus attention on the delimited area framed by the bar, than on two distinct areas framed by the squares. Thus, in our study it was easier for the subjects to focus on the temporal onsets of the grouped target stimuli, compared to those of the control stimuli. Our finding is in line with previous research suggesting that attentional resources are more concentrated inside a delimited area than outside it (Galera et al., 2006). Finally, in the present study visual grouping acted as a guide to assist in focusing attention on distinct objects within a specific framed area, thus it improved temporal discrimination of the objects of focus. Conversely, in the study by Nicol and Shore (2007), the distinct objects themselves formed one visually unified object, which made it more difficult to discriminate between their temporal onsets. We assume that in their experiment most of the subjects' attentional resources were required for discrimination between the spatial properties of the stimuli that were presented. That might have caused the reported decreased performance in temporal discrimination. In sum, visual grouping can either improve or impair temporal resolution, depending on the experimental design that is applied. More research needs to be done on the different kinds of visual grouping. Previous research has shown that attention to temporal properties of a stimulus can be enhanced by using a warning signal which appears with a constant foreperiod before the onset of the imperative stimulus to be judged (Bausenhart et al., 2008). Results of our study are in line with this finding given that an abrupt background stimulus presentation produced better performance than a persistent one. Therefore, we suggest that the foreperiod paradigm is a useful method to induce temporal attention which could lead to higher temporal resolution. Bausenhart et al. (2008) proposed that a higher rate of information sampling in the perceptual system, which is associated with temporal preparation induced by a warning signal, might lead to increased temporal resolution.Vidal et al. (2006) suggested gamma-band oscillations in the 44-66 Hz range as a neural basis of focused attention. Taking these findings into account, we propose gamma band oscillations as a possible underlying neuronal mechanism for increased temporal attention. Moreover, Varela, Toro, John, and Schwartz (1981) found evidence that perception of visual events is tightly related to brain oscillations. In their EEG study, two flashes of light were presented always with the same SOA at different phases of the subjects' ongoing alpha rhythms. If the flashes were judged on a particular phase as simultaneous, then at the opposite phase which was separated by 180° they were judged as sequential as shown in a model of perception suggested by VanRullen and Koch (2003) (Figure 23).

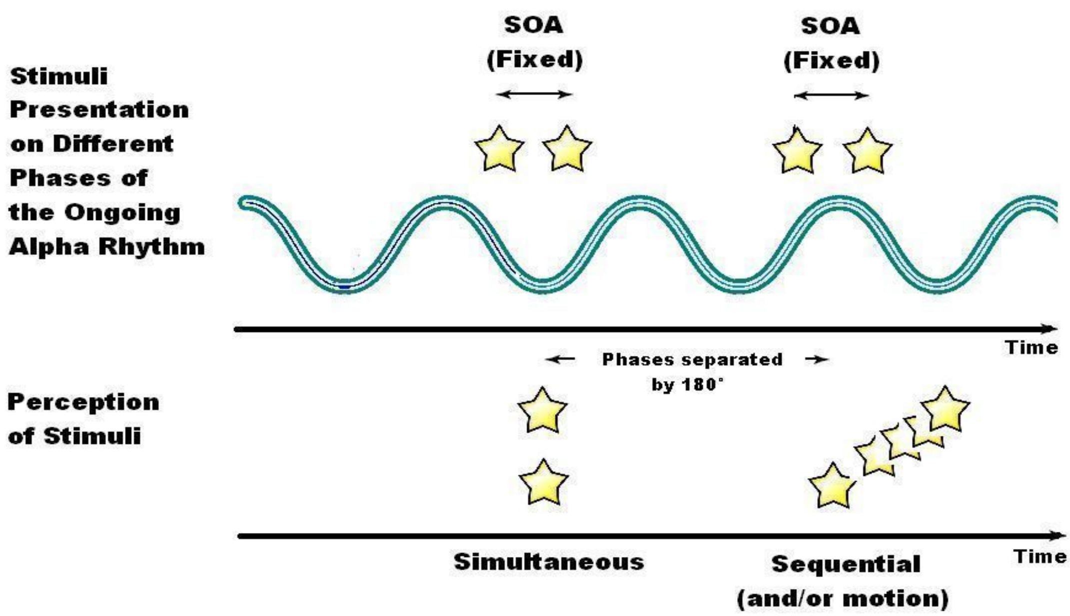

Figure 23.
Perception Model adapted from VanRullen and Koch (2003) based on results of a study by Varela et al. (1981). According to their model, two stimuli with a fixed SOA can be perceived either as simultaneous or sequential depending on when they are presented relative to the ongoing alpha rhythm. The perception of two successive stimuli goes from simultaneous to sequential for phases that are separated by 180°.

VanRullen and Koch (2003) suggest that so-called Multiplexing Representations could explain how interactions between superimposed slow and fast neuronal rhythms participate in forming visual perception. According to their hypothesis, fast wave representations in the gamma band would constitute the contents of individual discrete snapshots, while slower waves in the alpha or theta band would constitute the whole percept. As mentioned in Chapter 1, time appears to expand during or just before car accidents, according to subjective reports of people who were involved in such extreme situations (Tse et al., 2004). Previous research suggested that time's subjective expansion (TSE) can be attributed to the interference of attention and its influence on the amount of perceptual information processed (Mattes & Ulrich, 1998; Tse et al., 2004; Xuan et al., 2007). We take the results of these studies one step further by integrating them in a novel model for visual perception drawing on the findings of the present research shed possible light on the phenomenon of increased temporal resolution during TSE (as shown in Figure 24), which motivated this study to be undertaken.

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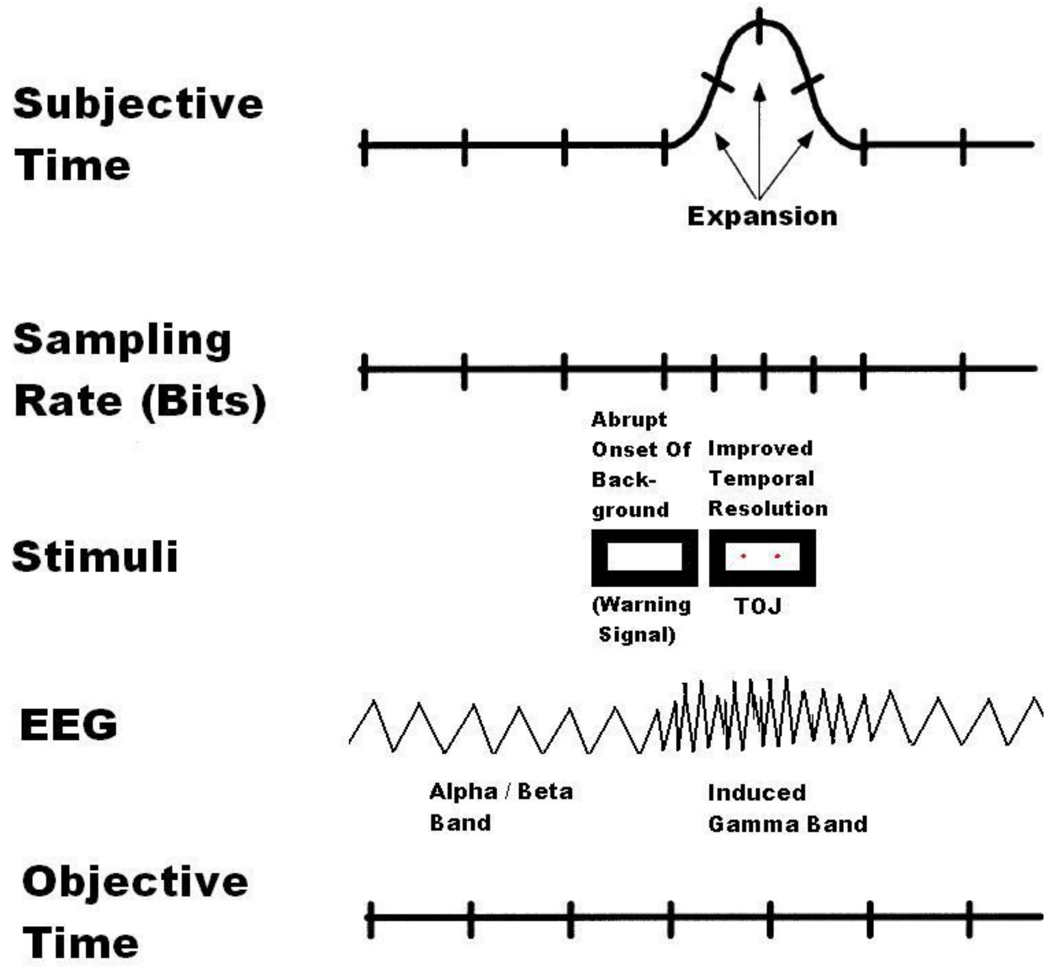

Figure 24.
Proposed model of improved temporal resolution during time's subjective expansion (TSE). EEG frequency in the gamma band is induced by the abrupt onset of the background stimulus which is perceived as akin to a warning signal. This leads to increased perceptual information processing of the stimulus per unit of objective time. Thus, time not only seems to expand subjectively relative to objective time, but temporal resolution is also increased.

Although not yet verified using EEG (a plan for future research), in our model, neural oscillations in the gamma band are induced by the abrupt onset of the background which is perceived as akin to a warning signal. We propose that gamma oscillations are an underlying mechanism for higher rates of information sampling in the perceptual system leading to improved temporal resolution during TSE as shown in Figure 24.

Results of the present study reveal that visual grouping and temporal attention in combination improve temporal resolution of the visual system more than if either of them is present separately. Kahneman and Henik (1977) suggest a hierarchical model to explain the relation between attention and perceptual grouping. According to their model, attention is first allocated to a group as a whole, and subsequently to elements within that group. Results of their study (see Chapter 2.2) suggest that attention can be focused more effectively on multiple relevant items if these are spatially grouped. Taking into account the findings of their study and the present study, we suggest a simplified model of the visual system using an example of the face recognition system of modern digital cameras. We suggest that this example explains figuratively how interactions between visual grouping, temporal attention and temporal resolution can be conceived (Figure 25).

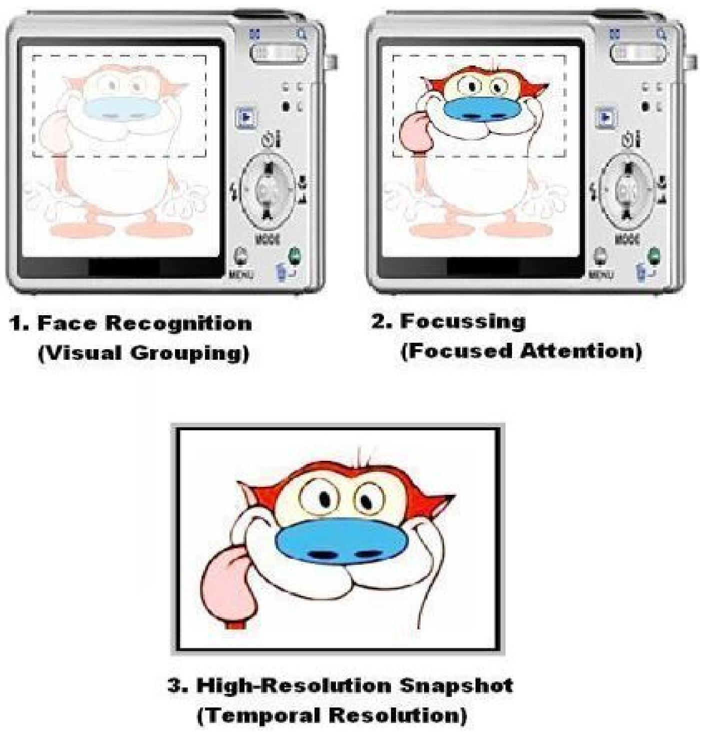

Figure 25.
Proposed model for interactions between visual grouping, focused (temporal) attention and temporal resolution in the visual system based on the example of the face recognition system of modern digital cameras.

According to the proposed model (not yet tested) as shown in Figure 25, first the relevant visual elements which belong together become grouped and segregated from their background by the face recognition system of the camera. This process symbolizes visual grouping as it happens in the human visual system. Second, the camera takes the grouped elements into focus and increases their resolution. This process accounts for the allocation of attentional resources in the visual system to relevant grouped elements. Third, a snapshot with high resolution is taken, symbolizing a period of improved temporal resolution (e.g. during TSE) in the visual system as a result of the preceding processes. We suggest that grouping elements of a scene into meaningful objects makes it easier to attend to them, which is in line with previous research suggesting that coherent precepts are more likely to catch attention than incoherent ones (Vidal et al., 2006). Moore and Egeth (1997) suggest that substantial perceptual organization precedes the allocation of attention within a visual scene and that attention is required to consciously encode the results. These findings indicate that visual grouping in particular might happen pre-attentively, while the relation between attention and grouping appears to be reciprocal. Moreover, a common mechanism most likely underlies the interactions between grouping and attention in the visual system, in a manner similar to a camera where the battery is the source providing energy for object recognition and focusing. Thus, in line with Vidal et al. (2006), we suggest that gamma-band oscillation is a common neural basis for focused attention and visual grouping, where attention is associated with the low gamma band (44-66 Hz) and grouping processes with the high gamma band (70-120 Hz).

5.3 Impact of the Current Results on Temporal Perception and Suggestions for Further Research

Showing that TOTs were lower in the grouping conditions than in the control conditions, our results are in line with some previous research (Vidal et al., 2006; Xu & Chun, 2007), but contrary to other research (Nicol & Shore, 2007). By analysing these contradictory findings we revealed that there are different kinds of visual grouping which can either impair or improve temporal resolution. This finding might be very important for further research on visual grouping. It would seem that more differentiation needs to be considered on the grouping paradigms that several tasks employed. One possibility would be to directly compare the various grouping paradigms and their influences on temporal resolution within one experiment. Moreover, additional EEG recordings could reveal interesting findings about the neural basis of cognitive strategies used by the brain under those conditions. That is a goal of our future research.

Our results regarding the influence of temporal attention on temporal resolution are in line with previous research (Bausenhart et al., 2008; Correa et al., 2006). The subjects' TOTs in the present study were lower when temporal attention was induced by warning signals with constant foreperiods compared to the control conditions where no such cues were applied. A warning signal is not by any means an extreme event like a car accident; thus it does not induce anywhere near the intensive slow motion perception such as several people have reportedly experienced just before a car accident (Tse et al., 2004). However, results of the present study clearly support previous research suggesting that time's subjective expansion (TSE) can be attributed to the interference of attention and its influence on the amount of perceptual information processed (Mattes & Ulrich, 1998; Tse et al., 2004; Xuan et al., 2007). Therefore, the present results might shed some light on the question raised by Tse et al. (2004). That is, by making novel or important events appear to occur in slow motion, those events may indeed be processed in greater depth per unit of objective time than are normal events. Further research on TSE could reveal interesting findings by using experimental designs which contain extreme stimuli like pictures of spiders presented to people uncomfortable with them to induce temporal attention while measuring temporal resolution. Moreover, with the addition of EEG recordings it could be determined whether neural oscillations in the gamma frequency band are associated with increased temporal resolution during TSE as was suggested in our model in Figure 24 and hope to verify in future research.

By using a novel experimental design we were able to test the relations between visual grouping, temporal attention and temporal resolution. Results obtained from the experiment revealed a reciprocal relation between visual grouping and temporal attention. For the first time, we found that temporal resolution was best when visual grouping and temporal attention were present and worst when both were absent. We suggested a simplified model based on the face recognition system of modern digital cameras to explain the mechanisms behind those processes in the visual system as shown in Figure 25. One future direction might be to develop computational models based on neural networks to simulate the interactions between visual grouping, temporal attention, and temporal resolution in the visual system.

No statistically significant results were found on the particular manipulation applied in the present study which was designed to address the subjects' cognitive strategies for temporal discrimination. It was proposed that giving them different instructions for TOJ might result in different effects on TOTs. We suggest that the instructions alone were likely not effective enough to evoke significant differences in increased early or late information processing in TOJ. However, future research could apply experimental designs where subjects are asked to report after each trial whether they were guessing or if they were sure in their judgments about temporal order of the presented stimuli. Thus, the transition from conscious to unconscious visual perception of temporal events could be more clearly determined. Melloni, Molina, Pena, Torres, Singer, and Rodriguez (2007) found that unconscious perception of stimuli in a masking task was associated with local gamma oscillations in the EEG, while consciously perceived stimuli were associated with synchronizations of gamma oscillations across widely separated regions of the brain. Given that, we suggest that a further experiment with an experimental design similar to ours with the addition of EEG recordings could reveal novel information about the signatures of neural activity of conscious and unconscious processing in temporal perception. Moreover, one group of the suggested experiment could be subjects with meditation experience. Brown, Forte, and Dysart (1984a, 1984b) found in their studies that those who practice meditation became aware of some of the usually pre-attentive processes which are involved in visual perception of temporal events. After completion of a 3-month meditation retreat they were able to consciously perceive shorter time intervals in a temporal discrimination task compared to before they started practicing meditation. With our proposed experiment, one could test whether practicing meditation causes a shift from unconscious to conscious processing of temporal perception. Additionally, EEG recordings should reveal how that shift would be associated with local gamma oscillations or global synchronizations of gamma oscillations in the brain.

5.4 Conclusion

In summary, this study has generated interesting and novel findings about the influence of visual grouping and temporal attention on temporal resolution. We found that temporal attention enhances temporal resolution, which is in line with the majority of the findings in this area of research. Furthermore, we found that visual grouping enhances temporal resolution. Some previous research on the influence of visual grouping on temporal resolution revealed findings which are contrary to ours. However, after further analysis of those contrary results we made the important point that there are different kinds of grouping paradigms which can either enhance or impair temporal resolution. This proposal is very important for further research in this area suggesting that the various kinds of visual grouping should be further characterized and differentiated. Furthermore, with our novel experimental design we were able to test the interaction between visual grouping, temporal attention and temporal resolution, showing that temporal resolution is highest when visual grouping and temporal attention were present in combination and lowest when both were absent. We provided a model based on functions of modern digital cameras which implement mechanisms of the face recognition system suggesting a reciprocal relation between visual grouping and temporal attention in the visual system. Taken together, all three hypotheses of this study were verified successfully. Moreover, we found evidence that temporal resolution is indeed enhanced during TSE. We also proposed a possible unified model for TSE suggesting neural oscillations in the gamma band as an underlying mechanism, based on clues from previous research.

In sum, all expectations from the present study were fulfilled. Moreover, we have brought forth novel and important findings about the influence of visual grouping and temporal attention on temporal resolution. The execution and results of this study evoked many new ideas for further research in this field. Overall, the present study provides a solid basis for many possible future experiments on temporal attention, visual grouping, temporal resolution, and their interactions, and on the phenomenon of TSE.

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Appendix A

Response Board

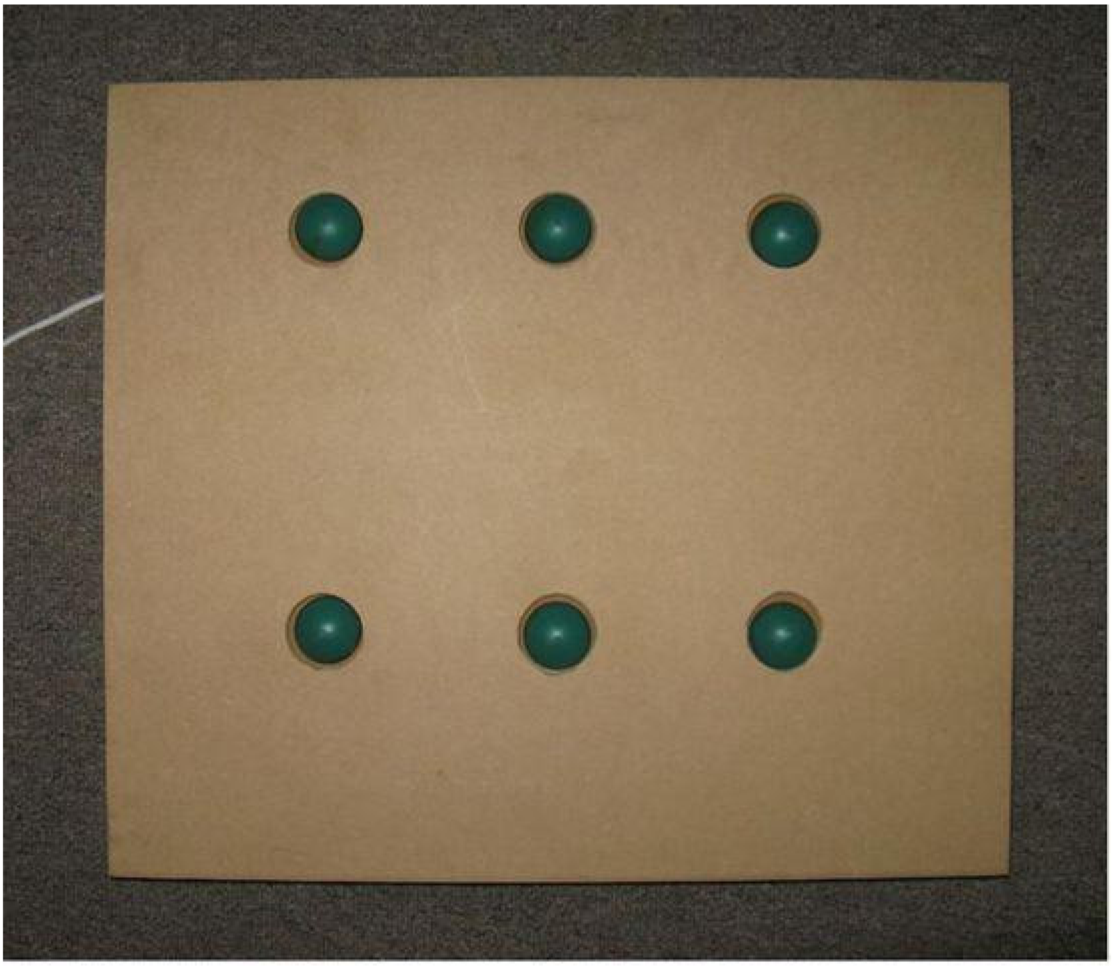

Figure 1.
Purpose-built response board used in the experiment. The buttons were used as described in Chapter 3 Methods (Figure 3) throughout the whole study. The response board was covered by a black rubber mat and placed in the mirror box below the light-semipermeable mirror.

Appendix B

Information Sheet for Participants

UNIVERSITY of OTAGO

SAPERE AUDE

Te Whare Wānanga o Otāgo

Making time judgements

Information Sheet for Participants

We would like to invite you to take part in a study that we are conducting. This study investigates time perception.

What will I be doing?

If you take part, you will be asked to do the tests at our lab in the Department of Psychology, University of Otago. If you are from the Psychology subject pool, then you do not receive additional payment. If you are from student job search, you will receive payment in the amount of $12.50 for our 1-hour session. You will be asked to sit in a dark laboratory booth and view stimuli that occur visually. You will also be asked to produce responses depending on how you perceive the stimuli. We will also be asking some subjects if they are interested in participating over repeated sessions (up to 4). If you are one of them, you have a choice of whether to do the repeated testing or if you would rather just attend one session. Of course, with repeated testing, subjects get payment for each hour.

Why is this study being conducted?

We are interested in basic time perception effects. Our experiment addresses this question in a different way than previous experiments because our stimuli are not always just small lights, but some are slightly more complicated shapes. We think that in the real world of shapes, maybe time perception is slightly different than with simple little lights.

Are there any benefits or risks?

The study does not have any direct benefits for you. The procedures used in the study have no known expected risks or harmful effects.

Who is participating in this study?

People who have no cognitive-processing related problems will participate in this study, as well as people who have meditative experience. Volunteers in this study need to be at least 18-years-old, to be able to speak and read English, and to be free of other conditions (like brain injury, epilepsy, or problem drinking) that may affect thinking skills. If you have such a condition, please either let us know or tell us that you probably should not participate.

What if I don't want to keep being part of the study?

If you agree to take part in this study you are free to discontinue (quit) being part of this study at any time. If you quit you will still receive your reimbursement for any session you have begun.

Can I have a support person with me?

If you would feel more comfortable having a support person or whanau member with you at any stage of the study, that person is most welcome to come with you.

What information will be collected and what will happen to it?

Your scores from the tasks will be collected. Scores (with no identifying information about you) will be collated with everyone else's scores. The investigators will look at the relationship between the scores on different tasks and between different groups. There will be no information with this data in which the person could be identified.

Only the investigators will have access to any information about you. Your scores will be labelled with an ID number rather than your name so an individual's performance is not looked at directly and so that you or your scores will not be able to be personally identified. The scores and the relationships found between the scores will be written about in a student's thesis and ideally they will also be published in a journal. You and other participants can be sent a summary of the results. Any information that is collected will be destroyed after 10 years.

Other Queries

If you would like more information about this study or have any questions, before or after participating, please feel free to contact one of us:

— Armin Keller, Investigator Tel.: 479-5778

— Associate Professor Liz Franz (supervisor) Tel.: 479-5269

Our postal address is: Department of Psychology, University of Otago, P. O. Box 56, Dunedin.

If you have any queries or concerns regarding your rights as a participant in this study you may wish to contact a Health and Disability Advocate. An advocate can be contacted on (03) 479 0265 or 0800 377 766. If there are specific Maori issues/concerns please contact Linda Grennell on 0800 377 766.

Thank you for your interest in our research.

Department of Psychology – Action, Brain, and Cognition Laboratory

PO Box 56, Dunedin, New Zealand.
Tel 64 3 479 5269

This project has been reviewed and approved by the University of Otago Ethical Committee.

Appendix C

Participation Consent Form

UNIVERSITY of OTAGO

Te Whare Wānanga o Otāgo

Making Time Judgements

Participation Consent Form

I have read and I have understood the information sheet for people volunteering for the study on decision-making and response actions. I am satisfied with the answers to any questions I asked.

- I understand that being part of this study is voluntary.
- I understand that I am able to stop being part of the study at any time, even if I have not taken part in the whole study. Those running the study will support such a decision.
- I understand that my involvement in this study and any information recorded is private. No material will have any details on it that will identify me.
- I understand that what I am being asked to do is not harmful, but if I am uncomfortable with any part of the questioning or computer experiment it will stop.
- I understand that the information collected will be held for a maximum of 10 years.

I understand and am happy with the information mentioned above.

Signed: ……………………………………………………………

Name: ……………………………………………………………

Date: ……………………………………………………………

I would like to receive a summary of the results **YES** **NO** (Please Circle)

I consent to the data about my performance in this study being presented as a case-study (if necessary) **YES** **NO** (Please Circle)

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Appendix D

Level of Difficulty Form

Level of Difficulty (Scale 1-10)

Temporal Order Judgment Task

Subject Nr.:

Date:

Time:

Very Easy **Moderate** **Very Difficult**

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AM**	**Guess**
Block 1												
Block 2												
Block 3												
Block 4												
Block 5												
Block 6												
Block 7												

Appendix E

Edinburgh Handedness Inventory Form

Questionnaire for Bimanual Temporal Order Judgment Task   Subject no______

Edinburgh Handedness Inventory

Please answer the following questions.

1. Your age is ____________ .
2. Do you consider yourself right handed, left handed, or both?

For adults, on the following questions, put one tick in the column that indicates the hand you do these activities with. If you have a very strong preference to use one hand (or both hands), put 2 ticks in that column. If you have no experience with the activity, please leave them blank.

	left hand	right hand	both hands
1. writing			
2. drawing			
3. throwing			
4. using scissors			
5. using a toothbrush			
6. using a knife (without folk)			
7. using a spoon			
8. using a broom (upper hand)			
9. striking a match (adults only)			
10. opening a box lid (lid hand)			