UNIVERSITY OF BIRMINGHAM

THE INFLUENCE OF TASK-IRRELEVANT NAVON STIMULI ON THE TIME-COURSE OF VISUAL ATTENTION AND REACHING MOVEMENTS

by

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Abstract

The aim of this thesis is to examine the time-course of task-irrelevant interference effects in Navon letters. In Navon stimuli, a large letter is composed of small letters and results show that participants are generally faster when the letters are compatible. In the present work, instead of responding to letter identity, participants were required to respond to the luminance of the stimuli. This luminance discrimination task was implemented both when attention was directed to the global and when it was directed to the local level. In the global level task (chapter 2), participants were asked to respond to the luminance of a Navon letter. In the local level task (chapters 3 and 4), task-irrelevance was manipulated by asking participants to respond to the luminance of a dot that was embedded in one of the local letters. Time-course of responding was manipulated by using different luminance contrasts in different experiments. The results showed that participants responded faster when the global and local letter matched. Time-course seemed to be less influential as previously predicted (chapter 5). Finally, task-irrelevant interference effects on the local level were investigated by using a choice-reaching task (chapter 6). No interference effects occurred, neither for initiation latency nor for maximum deviation of the movement trajectory. In conclusion, the findings of this thesis suggest that in a reaction-time task, task-irrelevant interference effects in Navon letters can occur. This seems to be independent of the level of attentional focus.

Keywords: Navon task, Luminance detection, Task-irrelevant interference effects, Time-course of task irrelevant interference effects

Dedication

I dedicate this thesis to my grandad.

(Julia Wolska, May 2020)

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List of Abbreviations

ANOVA	**An**alysis **O**f **Va**riance
CRT	**C**hoice **R**eaching **T**ask
EEG	**E**lectro**e**ncephalo**g**raphy
ERP	**E**vent-**R**elated **P**otential
IL	**I**nitiation **L**atency
IES	**I**nverse **E**fficiency **S**core
IMA	**I**nitiation **M**ovement **A**ngle
MD	**M**aximum **D**eviation
N_{inc}	**N**egativity associated with **inc**ongruency
ms	**M**illi**s**econds
PFC	**P**re**f**rontal **C**ortex
RGB	**R**ed **G**reen **B**lue
RHT	**R**everse **H**ierarchy **T**heory
RT	**R**eaction **T**ime
SOA	**S**timulus **O**nset **A**synchrony
SSC	**S**timulus-**S**timulus **C**ompatibility
SD	**S**tandard **D**eviation
SRC	**S**timulus-**R**esponse **C**ompatibility

Chapter One: INTRODUCTION

1.1 Relevant frameworks

1.1.1 Attention

Visual attention is important in everyday life. If we did not pay attention to the most relevant objects but to everything that surrounds us, we would not be able to carry out all of our daily tasks efficiently. Attention therefore helps us to focus on the important objects and tasks in a given moment.

When talking about attention, it is important to give a definition of the word and all its different aspects. William James gave one of the first definitions in 1890 in "The Principles of Psychology" (pp. 403-404):

> Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what may seem several simultaneously possible objects or trains of thought. […] It implies withdrawal from some things in order to deal effectively with others.

Since the 1890s, more detailed distinctions have been made between all the different aspects of attention. For example, according to Eysenck and Keane (1997) it is important to distinguish between focused and divided attention. In a focused attention task, participants are required to only respond to one stimulus (in experimental terms referred to as the target) and to ignore the other stimuli (referred to as distractors) that are presented at the same time. In contrast, in a divided attention task, participants are required to process several stimuli at once. Divided attention tasks therefore provide information about processing limitations. Furthermore, it is important to distinguish between stimulus-driven and goal-driven attention (Yantis, 1993). When attention is stimulus-driven, then it is guided by certain characteristics of a stimulus. These can include saliency or novelty. It can be said that this type of attention is mostly called bottom-up processing or having an exogenous control over the locus of attention. Goal-driven attention, in contrast, means that information is selected upon a goal-defined criterion, which can mostly be referred to as top-down processing or having endogenous control over the locus of attention. Other authors (e.g. Reed, 2007) defined bottom-up processing as following: the flow of information goes from the sensory store to higher-order memory. In contrast, in top-down processing, higher-order memory processes restrict the flow of information that are received by the sensory store. Exogenous locus of control refers in the field of attention to the fact that orienting is stimuli-driven, whilst endogenous locus of control means that orienting is driven by factors within the observer (Johnson, & Proctor, 2004). This is also referred to as external and internal attention (Chun et al., 2011). While attention is characterised by those different aspects, the focus of this thesis is on the potential interference of irrelevant information, independently of whether this information was selected in a bottom-up or top-down fashion. Another aspect of attention that will be relevant for the set-up of this thesis is the time-course of attention, which is an important factor as attention does not happen instantly but evolves over time (e.g. Egeth, & Yantis, 1997).

1.1.2 Interference effects, automatic and controlled processing

Focused attention helps us to only respond to the task-relevant target and to ignore the task-irrelevant distractors. However, focused attention might be error-prone. This might result in the inability to ignore the task-irrelevant distractors, leading in turn to a longer detection time of the relevant targets. In other words, if focused attention fails to suppress distractors, those task-irrelevant distractors can lead to interference effects, resulting in longer response times to the task-relevant target. One classical example is the Eriksen flanker task (Eriksen, & Eriksen, 1974). In this experiment, participants had to indicate the identity of a letter (H, K, C, or S) by pressing the right or left lever press. H and K were associated with right lever presses, whilst participants had to press the left lever press for C and S. The letter was flanked by another letter which required the same response (congruent condition) or a letter which required a different response (incongruent condition). In the incongruent condition, reaction times (RTs) were slower than in the congruent condition.

On the other hand, interference effects occur when there are two competing responses that are both activated by a single task. The interference effect will depend on the potential relationship between the two responses (see, Kornblum, 1992; 1994). This can be illustrated with the Stroop task (Stroop, 1935). In the Stroop task, participants are asked to name the ink colour of a certain colour word. The ink colour and the colour word either match or do not match and responses are generally slower when they do not match, which is called the interference effect. It has to be mentioned that generally, reading the word does not lead to interference, even if it is written in a different colour. Typically, the interference effect in the Stroop task is explained through automatic and controlled processing (e.g. MacLeod, 1991). Whilst automatic processes are described as being fast, usually occurring without attention and occurring without participants' effort, controlled processes are described as being slower in time, requiring attention and requiring more effort (Shiffrin, & Schneider, 1977). Several other studies support the statement that automatic processes are fast whilst controlled processes are rather slow (e.g. Jansma et al., 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984). The fact that generally reading the word does not lead to interference whilst naming the colour does lead to interference if there is incompatibility between the word and the colour is explained by the assumption that reading is an automatic process, whilst colour naming is a controlled process (MacLeod, 1991). It is worth noting that this assumption was challenged by various researchers and it was found that, depending on the task, the Stroop effect can be eliminated or inversed (e.g. Besner et al., 1997; Dishon-Berkovits, & Algom, 2000; see Chuderski, & Smolen, 2016, for a review of studies).

In the context of task-irrelevant processing, it is also important to mention the Attention White Bear theory (Tsal, & Makovski, 2006). Participants were presented with flanker displays, which consisted of a central target and two diagonal distractors. The latter appeared at fixed locations. However, on a minority of trials, unexpected stimuli (dots or a line) appeared instead of the distractors. The dots could either appear at expected distractor or expected empty locations. Participants' perceived the dots to appear in the expected distractor location before they appeared in the expected empty location. The line was perceived to extend from the expected distractor locations to the expected empty location. The authors concluded that attention was allocated to the expected distractor locations before the stimulus appeared. Therefore, the authors suggested that attention is guided to expected locations of all stimuli, which happens independent of task relevance. This process is called "process-all mechanism" (Tsal, & Makovski, 2006, p. 351) and suggests that distractors are actively and attentively processed. The Attentional White Bear theory contributes to a high degree to the explanation of failure of selective attention because efficient selective attention would mean that attention is guided away from the expected distractor locations. The Attentional White Bear theory therefore challenges the assumption of automatic, involuntary distractor processing.

1.1.3 Cognitive control

The examples above suggest that in order to overcome interference effects, cognitive control is necessary. Cognitive control can be described as the inhibition of reflexive reaction to sensory information that may be immediate and salient in order to achieve higher-order goals (Miller, 2000). In visual attention experiments, this would mean that a salient distractor would trigger reflexive responses, but if cognitive control is efficient, then it can still be ignored in favour of the goal-relevant target.

It is important to note that controlled processes (such as naming the ink colour in the Stroop experiment) can usually only be carried out successfully if automatic processes (such as reading the word) can be suppressed. However, this suppression takes time, which explains the occurrence of interference effects (e.g. MacLeod, 1991). Neuroimaging studies showed that amongst other regions, the prefrontal cortex (PFC) is one of the brain main areas that is engaged during this suppression. This brain area is associated with cognitive control (e.g. Koechlin et al., 2003; Ridderinkhof et al., 2004; for a review, however, see Band, & van Boxtel, 1999). Derfuss et al. (2004) found that for incongruent trials in the colour-naming condition of Stroop task, the PFC shows higher activation compared to the word-naming condition. At the same time, RTs were still longer for incongruent trials, supporting the statement that controlled processes generally need time to overcome automatic processing.

However, there is evidence that efficient cognitive control does not necessarily lead to longer responses for incongruent trials. Examples for this can be found in clinical studies of patients with frontal lobe lesions. Vendrell et al. (1995) compared frontal lobe patients and control subjects in the Stroop task and only found differences in error rates, but not in RTs. Thompson-Schill et al. (2002) also did not find any differences in interference effects between frontal lobe lesions patients and control subjects, using a response inhibition task. On the other hand, Stuss et al. (2001) found increased interference effects for the colour naming condition in the Stroop task for patients with frontal lobe lesions. This suggests that efficient cognitive control does not necessarily lead to increased interference due to the necessity of overcoming response conflicts. In fact, White et al. (2018) linked greater interference to weaker or slower cognitive control. This theory was further supported by Bialystok et al. (2004), who used the Simon task to test bilingual advantage. In the Simon task (Simon, & Wolf, 1963), participants are asked to make a rightward response to one stimulus (e.g. a circle) and a leftward response to another stimulus (e.g. a square). The location of the stimuli on the display varies, meaning that a circle can be presented on the right side (congruent condition) or on the left side (incongruent condition). Responses are usually faster in the congruent condition, when stimulus and response features match in terms of location. In incongruent trials, responses are usually slower. The difference between RTs for incongruent and congruent trials is the Simon effect. Bialystok et al. (2004) found a smaller Simon effect for bilinguals, which they link to more efficient cognitive control, as several studies found before that bilingualism is linked to higher levels of cognitive control (see Bialystok et al., 2009, for a review). Coderre and van Heuven (2014) also link successful executive (cognitive) control to less interference. They tested bilinguals and monolinguals in a Stroop task and found reduced conflict-related event-related potential (ERP) amplitudes in bilinguals, hereby suggesting a bilingual-specific advantage of ignoring or suppressing distracting information (however, see for example Paap, & Greenberg, 2013, Paap et al., 2015, for contrasting results).

Thus, there are two important conclusions so far. First, due to cognitive control mechanisms, an interference effect occurs. This is because cognitive control is necessary to overcome distracting information but the suppression of distracting information does not happen instantly. Second, efficient cognitive control can also reduce interference effects. This shows that there are two different ways of conceptualising cognitive control. Braver et al. (2007) explain those two ways with the dual mechanisms of cognitive control framework, which differentiates between proactive and reactive cognitive control. Reactive control takes place as a late correction, after interference is detected. Proactive control, in contrast, aims to minimise interference before it occurs. Therefore, longer response times for incongruent trials can be explained by reactive control, because conflict is detected. Reduced interference effects, on the other side, do not simply mean more efficient cognitive control, but they reflect proactive cognitive control. Interference is anticipated and ameliorated before its occurrence.

1.1.4 Bottleneck theory

The bottleneck theory provides another approach to explain the occurrence of interference effects. Broadbent (1958) stated that human cognition is limited and when input outstretches capacity, then only the most salient or relevant stimulus will be processed, just like in a ‘bottleneck’. When referring to this theory, it is important to distinguish between early selection and late selection. Early selection models focus on physical properties when selecting information for further processing (Broadbent, 1958), whilst late selection models would suggest that selection occurs after stimulus identification (Deutsch, & Deutsch, 1963; Norman, 1968). In Broadbent’s (1958) early selection model only the most relevant information reaches the bottleneck and passes through it, whilst unattended information are completely blocked out. In contrast, Treisman (1960), who like Broadbent used an auditory task, proposed an attenuation model that consisted of two parts – a selective filter and a ‘dictionary’. As in Broadbent’s (1958) model, the information is selected based on physical properties. However, according to Treisman (1960), the unattended message (which was a word) is not blocked but attenuated and passes through the filter if the word exceeds the threshold. This explains why usually little is heard if the words are unattended but occasionally some words are recognised. Finally, Deutsch and Deutsch (1963) and Norman (1968) proposed a late selection model, in which they stated that the bottleneck occurs after pattern recognition, when information is selected for short-term memory. These three models led to many experiments and arguments around the location of the bottleneck, with contradictory evidence (see Reed, 2007, for a summary). Johnston and Heinz (1978) proposed a multimode theory of attention, according to which the participant has control over the bottleneck and can adopt it according to the demands of the task. In this context, it is also important to mention the perceptual load theory, which was presented by Lavie (1995) as a potential solution to the early vs. late selection debate.

Perceptual load refers to the physical complexity of stimuli, mainly the distractor stimuli. A red square surrounded by blue circles would refer to a low load condition, whilst a red square surrounded by red and blue circles would refer to a high load condition. It is assumed that a high load condition requires more attentional resources and therefore the target will be selected sooner and the distractors will be quickly filtered out, which refers to early selection. In contrast, in a low load condition, more of the distractors will be processed because attentional resources are still available. Therefore, in this condition, late selection occurs. Despite the usefulness of the perceptual load theory, there has been also some criticism. For example, it has been argued that perceptual load is defined by paradigms instead of visual processing. Furthermore, researchers have stated that it is difficult to detach perceptual from cognitive load (see, Murphy et al., 2016, for a review).

The bottleneck theory has been tested amongst others in dual-task experiments, where participants have to execute two different responses to tasks that are presented in rapid succession. For example, in Pashler's and Johnston's (1989) experiment, the first task was to indicate whether an auditory tone was high-pitch or low-pitch by using their left hand, whilst in the second task, participants had to respond with their right hand to the identity of a letter. In Kunar's et al. (2008) experiment, participants had to maintain a conversation on the telephone or listen to a narrative while being engaged in a task that required sustained visual attention. The time interval between the presentation of the first and the second stimulus is called stimulus onset asynchrony (SOA; Pashler, 1994). Generally, RTs to the second task are longer, which can be explained by the psychological refractory period, which states that the response to a second stimulus is delayed because the first stimulus is still processed (e.g. Pashler, & Johnston, 1989; Smith, 1967; Welford, 1952; see Pashler, 1994, for a review). There are two main models explaining this effect. Postponement models assume that the bottleneck consists of a single channel, which delays processing stages in the second task. On the contrary, capacity-sharing models state that processing occurs for both tasks at reduced rates because common resources are shared (Pashler, & Johnston, 1989). However, the extent to which both tasks can be performed at the same time depends on the demands of both tasks (Eysenck, & Keane, 1997). This yields into the capacity theory proposed by Kahneman (1973), which states that interference occurs when the demands of two tasks exceed the available capacity and which was proposed as an extension of early or late selection bottleneck theories.

The bottleneck theory has also been used to explain the Stroop effect. Stafford and Gurney (2007) proposed a response-selection bottleneck-theory for the Stroop task, which is an extension of the other theories explaining the Stroop effect, as the previous explanations did not focus on the response-selection stage. Stafford and Gurney (2007) assumed that the automatic response of word reading arrives earlier in the bottleneck, triggering a response, which then causes delay in the response execution of the correct response of colour naming. This argument is further strengthened by manipulating the SOA interval between colour and word onset (e.g. Appelbaum et al., 2012; Dyer, 1971; Glaser, & Glaser, 1982; Lu, & Proctor, 2001; Roelofs, 2010; Starreveld, & La Heij, 2017). These studies found that interference is generally greatest at around 0 SOA, meaning that interference occurs if the irrelevant stimulus appears before target processing is finished. Instead, at negative or positive SOA, one task can be finished before the other one reaches execution stage, which diminishes interference. Chuderski and Smolen (2016) provided further support to this theory by reviewing different neural network models of the Stroop task (e.g. Cohen et al., 1990; Roelofs, 2000; 2003) from which they concluded that reading words and naming colours can be seen as two separate pathways that compete for output and that these pathways are activated differently, which they compare to the “horse race model” (Logan, 1981), which states that inhibitory processes have to win a race against automatic, ongoing responses in order to be successful. If the ongoing response finishes before the inhibitory process takes place, the response is executed. However, if the inhibitory process finished before response execution, the response can be stopped (Logan, & Cowan, 1984). This refers directly to the bottleneck idea.

The bottleneck theory is relevant for the present thesis in terms of the occurrence of interference effects. In the present studies, the idea is that two independent tasks are competing for output and interference will depend on the relative processing time of the two processes.

1.2 Navon task: Introduction into the experiments of this thesis

1.2.1 Navon task

The experiments in this thesis are based on the Navon task (Navon, 1977; 1981), which reflects visual scene processing. More specifically, the Navon task reflects humans' ability to identify the whole of a visual scene as well as its local parts (e.g. Baisa et al., 2019; Chamberlain et al., 2017). In the Navon task, a large stimulus made out of smaller stimuli is presented, for example a large letter made out of smaller letters. The letters are either congruent (the big and the small letters are the same) or incongruent, which means that the big and small letters are different (e.g. Heinze, & Münte, 1993; Martin, 1979; Navon, 1981, see figure 1).

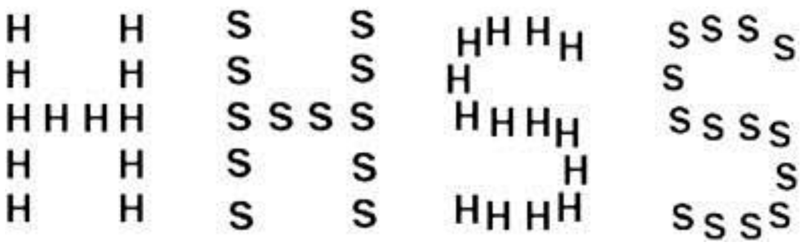


Figure 1: Original Navon stimuli
From left to right: A congruent global H, an incongruent global H, an incongruent global S and a congruent global S. This figure represents the original Navon stimuli (1981).

In these experiments, participants are asked to indicate the letter identity either on the global (by responding to the large letter) or on the local level (by responding to the small letter). Generally, participants are faster when making responses on the global level, which provides evidence for global precedence (e.g. Hughes et al., 1984; Navon, 1977; 1981; Paquet, & Merikle, 1988). In the Navon task, participants are also usually faster when the letters are congruent, which is called the congruency effect (Navon, 1977; 1981; Miller, & Navon, 2002). Incongruence on the global and local level leads to longer RTs when participants respond on the local level. Lamb (1996) and Navon (1977; 1981) could not demonstrate this incongruence effect when making responses on the global level: incongruence between the global and the local level did not lead to longer RTs. This is also usually termed global precedence (e.g. Lachmann et al., 2014). This is usually interpreted as evidence for scene processing from the global to the local level (e.g. Hochstein, & Ahissar, 2002). However, under certain conditions, participants respond faster on the local level, which is termed local precedence. Martin (1979) showed that responses are not always faster to global stimuli but that they depend on the number of local elements: global precedence only occurred for many-element patterns (e.g. a global S consisting out of 19 local Ss), whilst local processing took place for few-element patterns (e.g. a global S consisting out of 11 local Ss). Grice et al. (1983) also showed that participants only made faster responses on the global level when the stimulus was presented peripherally in an unpredictable way. Lamb and Robertson (1988) provided further evidence that the elimination of locational uncertainty leads to a disappearance of faster responses on the global level, whilst Heinze and Münte (1993) showed that faster responses on the global level depend on the visual angle (see Kimchi, 1992, for a critical review of local precedence effects). In addition, conflicting stimuli have been proven to lead to interference when responding to both the global and the local level and not just when responding to the local level (e.g. Hoffmann, 1980; Martin, 1979). This shows that the global precedence effect depends on certain characteristics that have to be met. Global and local precedence have been also studied when manipulating mood and emotions. For example, Bellaera and von Mühlenen (2019) showed that inducing fear broadens the attentional focus (which means that global precedence is induced), if combined with looming motion. Time-course has also been studied in global and local processing and the occurrence of interference effects. May et al. (2009) delayed the presentation of the global information relative to the local information (the global information being the whole global letter, S or H, and the local information being the middle-cross bar of the global letter) and found a global precedence effect at delays <48 milliseconds (ms) and a local precedence effect at delays >80 ms, whilst congruency effects were only found for 48 ms and 80 ms. Sanocki (1993) found that global primes were more effective early in processing, whilst local primes were more effective late in processing.

The interference effects in the Navon task are analogous to the interference effects that were discussed earlier, such as the Stroop effect, the Eriksen flanker task and the Simon effect. In all those experiments, participants are faster when the relevant and irrelevant stimulus match than when they do no match, albeit global and local letters (Navon task), ink colours and colour words (Stroop task), targets and flankers (Eriksen flanker task) or location (Simon task). There are some undisputed differences, such as that in the Navon task, the global and local letter appear in the same location, whilst in the Simon task, the key question is whether stimulus and response appear in the same location or not. Another key difference between those experiments is that the Navon task enables to examine interference effects on both the global and the local level. This investigation is not possible neither with the Stroop task, nor with the Eriksen flanker task, nor with the Simon task. Nevertheless, all these studies can be considered as examples for the automatic capture of visual attention by an irrelevant stimulus and the necessity of cognitive control to overcome this capture and to respond to the relevant target. Alternatively, these experiments can be approached from a bottleneck perspective, where two independent processes are competing for a response and interference occurs when those processes compete at the same time for a response.

1.2.2 The present study

Task-irrelevant interference effects have been widely used in the study of visual attention. This thesis aims to investigate whether Navon stimuli are automatically processed, i.e. whether an interference effect occurs even though the Navon stimuli are task-irrelevant. The focus of this thesis is task-irrelevant conflict, i.e. when the conflict between mismatching global and local level itself is irrelevant to the task. The first three experimental chapters explored this question with two different tasks. In the global level task (chapter 2), the task that will be relevant will be to indicate whether a Navon letter embedded in a square is brighter or darker than the square. In the local level task (chapters 3 and 4), participants will be asked to respond to the luminance of a dot embedded in one of the local letters. The tasks investigate the role of the focus of attention on performance. In chapter 2, the attentional focus is directed to the global level, whilst in chapters 3 and 4, the attentional focus is directed to the local level (figure 2).

This manipulation enables to study whether task-irrelevant interference effects depend on whether attention is directed to the global or to the local level. Those hypothesised interference effects could be described as ‘automatic’, because the task will consist of a task-irrelevant stimulus (the Navon stimulus) and attention would be captured by a different task, which will be relevant (luminance response to the Navon stimulus), similar to the studies discussed before when talking about interference effects (e.g. Stroop 1935; Eriksen, & Eriksen, 1974). In accordance with previous findings (e.g. Navon, 1977, 1981), it was hypothesised that congruent conditions would elicit faster responses whilst incongruent conditions would lead to slower responses, despite being task-irrelevant.

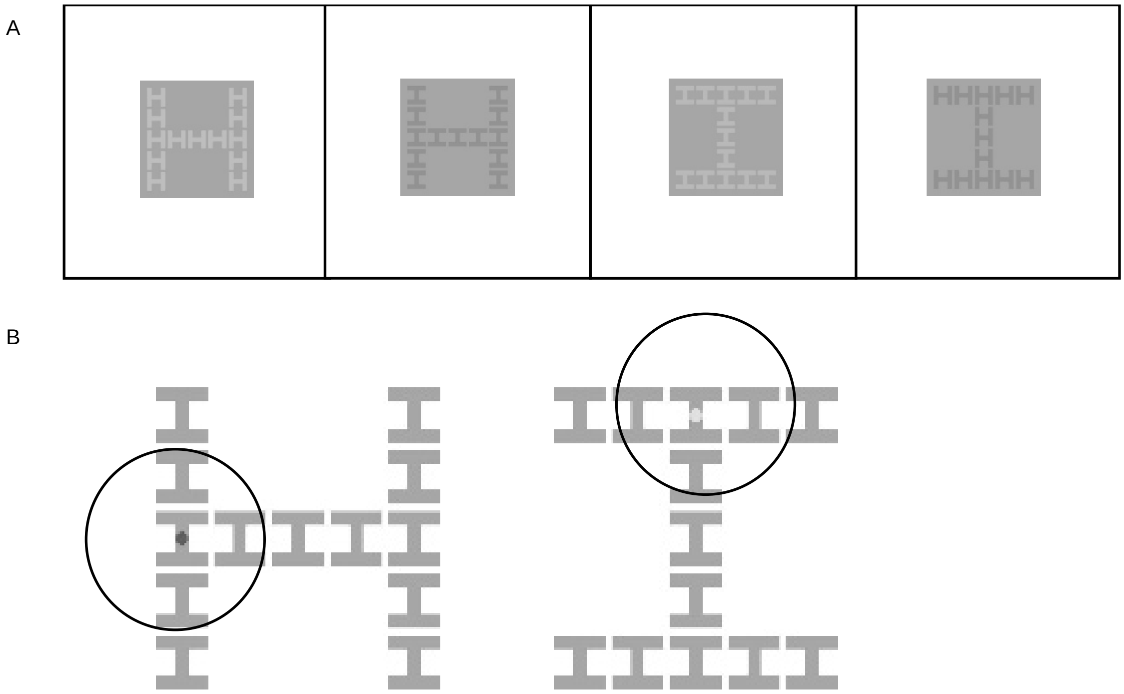


Figure 2: Global and local stimuli used in the thesis
A: Stimuli in the global level condition (chapter 2). B: Stimuli in the local level condition (chapter 3).

1.2.3 Effects of luminance contrast – ways to operationalise time-course

Some studies that examined the time-course of attention activation focused on the time-frame in which cues are most effective. For example, Müller and Rabbitt (1989) found that peripheral cues peak when there is a shorter time-difference between cue and target, whilst central cues peak when there is a longer time-difference. Theeuwes et al. (2000) showed that a salient distractor only disrupted performance when presented simultaneously with the target, whilst it did not disrupt performance when being presented before the target. This thesis however examines the time-course of attention by manipulating the luminance contrast of the task-relevant information, which will subsequently affect how quickly observers can discriminate the target. Several studies investigated the effects of luminance contrast on the time-course of responses and on accuracy, generally finding that dark stimuli are processed faster and more accurately than bright stimuli (e.g. Buchner, & Baumgartner, 2007; Komban et al., 2001). In addition, it has been shown that high luminance contrast generally leads to short RTs (Plainis, & Murray, 2000; Walkey et al., 2006). As specified in section 1.2.2, the aim of this thesis is to investigate whether interference effects in Navon stimuli occur when being task-irrelevant and the relevant task is the luminance decision. More specifically, participants will be asked to respond whether the letter is brighter or darker than its background in the global level condition or whether a dot embedded in one of the local letters is brighter or darker than the letter in the local level condition. The luminance manipulation of the discrimination targets enables insight into the time-course of RTs within an experiment, as the discrimination of dark targets is predicted to yield faster responses than the discrimination of bright targets.

Luminance contrast was further manipulated between experiments, making the contrast between bright and dark targets larger or smaller; in other words, making it easier or more difficult to respond. It was hypothesised that responses should be shortest for experiments with the highest luminance contrast condition and increase with decreasing luminance contrast (Plainis, & Murray, 2000; Walkey et al., 2006). Whether or not interference between letter processing and the luminance task occurred was predicted to depend on the relative time-course of both processes. This manipulation enables us to test the cognitive control theory. In the highest luminance contrast condition, responses were predicted to be so fast that automatic instead of controlled processing should take place. This should lead to increased interference effects, because efficient cognitive control should not yet be available to suppress those interference effects (e.g. Bialystok et al., 2004; Coderre, & van Heuven, 2014; Jansma et al., 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984; Shiffrin, & Schneider, 1977; Stuss et al., 2001; White et al., 2018). Contrary, in the lowest luminance contrast manipulation, responses were predicted to be so slow that controlled instead of automatic processing was predicted to occur throughout the whole experiment. This should lead to reduced interference effects, due to efficient cognitive control mechanisms (e.g. Bialystok et al., 2004; Coderre, & van Heuven, 2014; Jansma et al., 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984; Shiffrin, & Schneider, 1977; Stuss et al., 2001; White et al., 2018, see figure 3). The luminance contrast manipulation will also allow us to test the bottleneck theory. Specifically, it was predicted that if responses to luminance were done before the letter is processed in the highest luminance condition, this would prevent the occurrence of a bottleneck, and therefore no congruency effect should be observed. Similarly, in the lowest luminance condition, if responses to luminance were done after the letter is processed, hereby similarly preventing again the occurrence of a bottleneck, no congruency effect should be observed. This means that a reverse U-shape function for the bottleneck was predicted (Pashler, & Johnston, 1988, see figure 3). This luminance contrast manipulation (i.e. the difference between bright and dark discrimination targets) aimed to manipulate RTs between experiments.

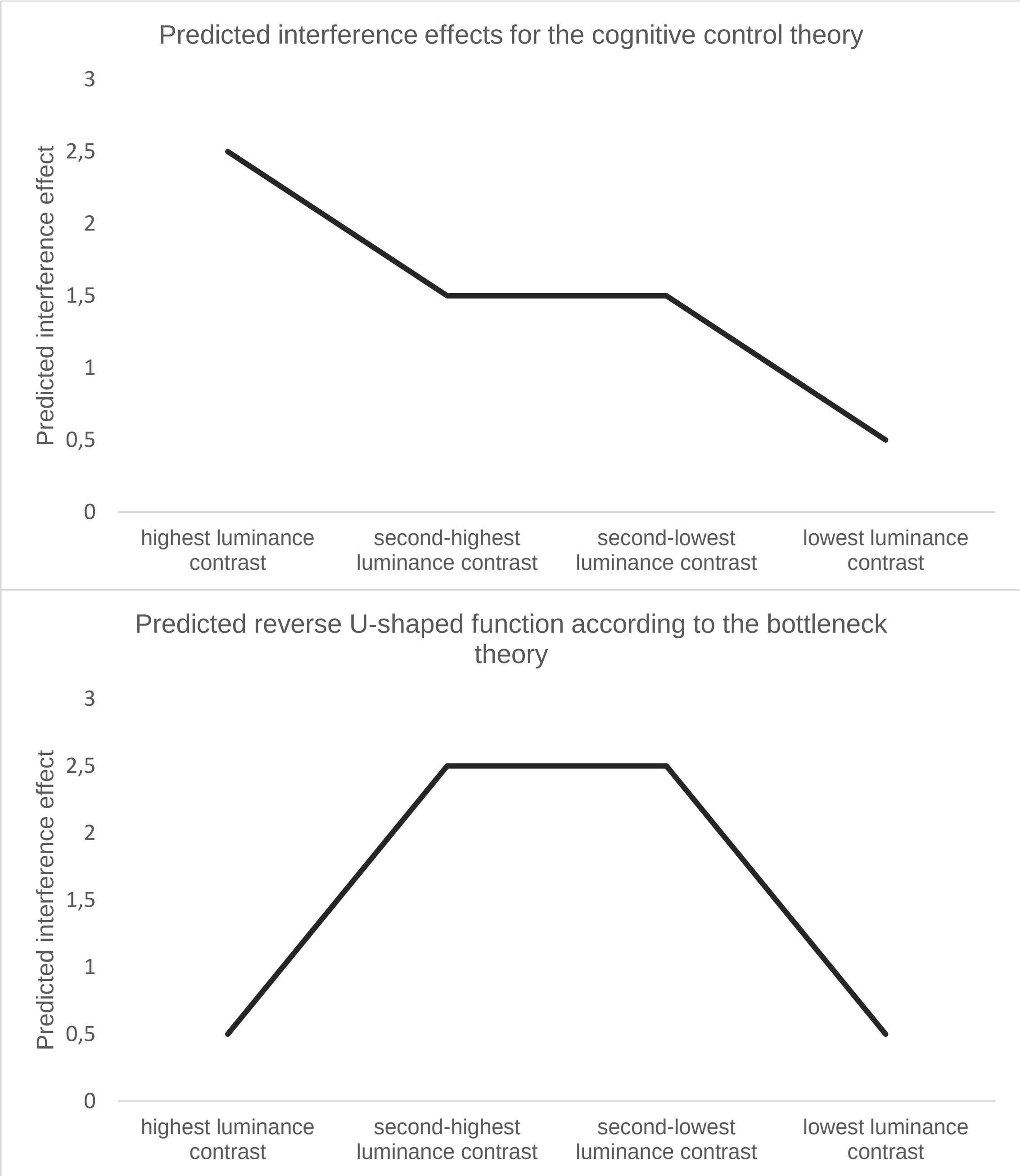


Figure 3: Predictions about the time-course of interference effects
Predictions about the occurrence of interference effects according to the cognitive control theory and the bottleneck theory.

1.2.4 Gestalt psychology

The Navon effect can also be explained by Gestalt psychology. The Gestalt psychologists Max Wertheimer, Kurt Koffka and Wolfgang Köhler proposed that humans perceive the whole of a visual scene as well as its local parts (Rock, & Palmer, 1990). One of the most important principles of Gestalt psychology is the law of Prägnanz (principles of grouping), which states that the human mind forms a global whole, which is more important than its (local) parts. Koffka (1935) stated it in the famous phrase “the whole is something else than the sum of its parts” (p.176), which is often incorrectly stated as “the whole is greater than its sum of parts” (Wong, 2010). The principles of grouping can be put in six categories (Rock & Palmer, 1990; Wertheimer, 1923; for a review see Wagemans et al., 2012):

1) Proximity: if objects are close, we perceive them as a group, even if they are different from each other;
2) Similarity: we perceive stimuli as part of the same object if they resemble each other and as part of a different object if they are not similar;
3) Closure: the human mind has a tendency to see complete figures or forms even if they are actually incomplete, which means that we tend to ignore gaps;
4) Good continuation: when there are intersections between two or more objects, then people usually perceive each object as a single uninterrupted object, which allows them to differentiate between stimuli;
5) Common fate: when we perceive visual elements as moving in the same direction at the same rate, then we see the movement as part of the same stimulus;
6) Good form: we have a tendency to group forms of a similar shape, pattern, colour etc. together.

The principles of Gestalt psychology have been mainly studied by using priming paradigms or visual illusions. For example, Moore and Egeth (1997) asked participants to report which of two horizontal lines was longer. The dots in the background, if grouped, formed the Ponzo illusion or the Müller-Lyer-illusion, so that the local parts were grouped as a global whole. The results showed that these illusions affected the responses on the line-length discrimination. The authors concluded that it can be therefore assumed that Gestalt grouping occurs without attention. Montoro et al. (2014) tested the effect of masked primes by introducing Gestalt patterns that were grouped either by proximity or similarity and induced a horizontal or vertical global orientation, again providing evidence for the formation of local parts to a global whole. Afterwards, participants were asked to respond to visible targets, which were either congruent or incongruent with the previous primes. The results showed reliable priming effects, but there were no differences between horizontal and vertical primes and targets. Another study that investigated congruency effects through grouping was carried out by Rashal et al. (2017). Again, grouping was rendered task-irrelevant to participants by asking them to identify a target and by finding out that participants did not attend the elements in the background. Congruency effects were operationalised by whether the display stayed the same or changed and performance was facilitated when grouping formed columns or rows by proximity, but not by shape similarity. Rashal et al. (2017) concluded that grouping by proximity, in contrast to shape similarity, does not require attention. Kimchi et al. (2018) investigated another Gestalt principle, luminance similarity and connectedness into vertically or horizontally oriented patterns, again by using priming. They found that both aspects of grouping can take place when the stimulus is suppressed from attention by sandwich masking, which is a combination of forward and backward masking. Han’s and Humphrey’s (1999) study is another example for the grouping of local parts to a global whole. They found that the strength of grouping between local arrows or triangles was gradually weakened by increasing the luminance contrast of background crosses.

In conclusion, all the studies that were just mentioned highlight that people tend to form local parts to a global whole, even if this process is task-irrelevant and they do not attend those stimuli. This shows that Gestalt psychology is relevant for this thesis. The principles of grouping lead to the conclusion that the Navon task should be a suitable experiment to study the effect of automatic task-irrelevant visual processing.

1.3 Compatibility effects

It is worth noting that interference or compatibility effects can occur at many levels and dimensions. In general, the idea is that that responses are quicker when two stimuli overlap (stimulus-stimulus compatibility) or the stimulus overlaps with the required response (stimulus-response compatibility), hereby diminishing interference effects (Kornblum, 1992).

1.3.1 Stimulus-response compatibility (SRC)

Task relevance and task irrelevance and its subsequent interference effects can be also explained with stimulus-response compatibility (SRC), which was first specified in detail in the dimensional overlap model (Kornblum, 1992; Kornblum et al., 1990). This model suggests that compatibility effects occur because of the dimensional overlap of a stimulus with a response. Dimensional overlap is defined as the extent of similarity between two items, either perceptually, structurally or conceptually. SRC effects occur for example in the Simon task (Simon, & Wolf, 1963), where participants are faster when the stimulus location (e.g. left or right side of the screen) overlaps with the response location (e.g. right or left hand). If the dimensions do not overlap, then responses to a certain stimulus are slower and more error prone (Kornblum et al., 1990). When stimulus and response overlap, then both dimensions can be relevant, but more interesting for the study of compatibility effects are cases where only the response might be relevant and the stimulus is completely irrelevant, as it is the case in the Simon task. Another example for SRC is the Eriksen flanker task, where participants make responses to a relevant stimulus, which is flanked by stimuli that belong to the same or a different response set. Flankers of a different response set delay the response to the relevant stimulus, despite being task-irrelevant (Eriksen, & Eriksen, 1974).

1.3.2 Stimulus-stimulus compatibility (SSC)

Another important part of the dimensional overlap model is stimulus-stimulus compatibility (SSC; Kornblum, 1992), which states that two stimulus dimensions overlap. In those cases, there is a relevant and irrelevant stimulus dimension. The Stroop task (Stroop, 1935) is a good example. The relevant stimulus dimension is usually the ink colour, whilst the colour word is usually the irrelevant stimulus dimension. The Navon task can be seen as another example of SSC, because participants are required to either make responses on the global or the local level, whilst the other stimulus dimension is task-irrelevant (e.g. Navon, 1977; 1981). Compatibility effects occur when both stimulus dimensions share the same characteristics. In the Stroop task, this means that the ink colour and the colour word match and in the Navon task, compatibility effects occur when the global and the local letter are the same. When the two stimulus dimensions do not share the same characteristics, then incompatibility effects occur.

1.3.3 8 types of SRC and SSC ensembles

Studying SRC and SSC has led to eight possible types of ensembles (Kornblum, 1994), out of which the type-6 ensemble corresponds to the stimuli used in this thesis:

1) Type-1 ensembles do not have any dimensional overlap, neither in the relevant nor in the irrelevant dimensions. Although those ensembles do not lead to compatibility effects, they are still useful for neutral, baseline or control conditions.
2) Type-2 ensembles have an overlap between the response and the relevant stimulus dimensions. For example, Fitts and Deininger (1954) showed that participants responded faster and more accurately to stimuli appearing in the left or right visual field when they used the spatially-compatible hand than with the spatially-incompatible hand.
3) Type-3 ensembles only overlap in terms of response and irrelevant stimulus dimension. In Simon's and Wolf's (1963) study, participants responded faster when the irrelevant stimulus and the response location were on the same side of the screen than when they were on opposite sides.
4) Type-4 ensembles only overlap in terms of the relevant and irrelevant stimulus dimension, as it is the case in the Stroop effect (Stroop, 1935).

5) Type-5 ensembles require a two-dimensional response set, where one dimension overlaps with the relevant stimulus dimension and the other one overlaps with the irrelevant stimulus dimension, whilst the two dimensions themselves do not overlap with each other. In Hedge's and Marsh's (1975) study, the stimuli and responses were either disposed vertically or horizontally, resulting in four possible combinations, where stimulus and response either overlapped or did not overlap. However, those combinations were task-irrelevant and relevant task was to respond to the colour of the stimulus. Similarly to Simon's and Wolf's (1963) study, the spatial distribution of stimulus and response (horizontal and vertical) had effects, in terms of participants responding faster when the locations matched.
6) Type-6 ensembles contain three-dimensional stimuli and one-dimensional responses: only the relevant stimulus dimension overlaps with the response, whilst there is no overlap between the response and any irrelevant dimension, but there is overlap between the two irrelevant stimulus dimensions. According to Kornblum (1994), there are no studies with this type of ensemble and literature search suggests that this is still the case. Our study would correspond to this type of ensemble: the relevant stimulus dimension (luminance of the letter or a dot embedded in one of the local letters) would overlap with the response (luminance decision), whilst the global and the local letter would not overlap with the response. However, the two irrelevant stimulus dimensions of the letter would overlap.
7) Type-7 ensembles also have three-dimensional stimuli and responses with one dimension. The relevant stimulus dimension does not overlap with the response, but there is overlap with an irrelevant stimulus dimension. The third irrelevant stimulus dimension does not overlap with the two stimulus dimensions, but it does overlap with the response. Kornblum, (1994) conducted a study, where a colour word was shown as a prime, which matched or did not match the colour that was the target. At the same time, the location of the colour word could match the side of the response. This resulted in conditions where the colour and the location of the response could match or mismatch. In other conditions, the colour word could match with the colour

response but the location would conflict with the response. Similarly, the location of the colour could match the side of the response, but the colour word and colour response could conflict.

8) Type-8 ensembles have an overlap of the response set with both the relevant and the irrelevant stimulus dimension and those stimulus dimensions also overlap, which is the case in the classic Stroop-task and its following studies as well as in the Navon task (e.g. Navon, 1977; 1981).

1.3.4 Time-course of SRC and SSC effects

It is important to mention that irrelevant stimulus dimensions are processed differently, depending on whether they overlap with the response or the relevant stimulus dimension. Kornblum (1994) showed that SSC effects could only be obtained when the stimulus was shown 200 ms after the prime which was presented before the stimulus, whilst for SRC effects this time difference did not matter. This was replicated by Kornblum et al. (1999). For type-7 ensembles, a similar pattern could be found (Kornblum, 1994). Other studies also showed effects of time-course on SSC and SRC. For example, it has been shown that the Stroop effect is minimal for fastest responses but increases with increasing response latency (Bub et al., 2006; Cohen et al., 1990; Glaser, & Glaser, 1982). If the modified Navon paradigm used in this present thesis leads to a similar interference effect as that typically found in Stroop studies, we expect to find a similar time-course. This means that the interference effect should increase as a function of response latency. This would suggest that letter identity might be increasingly disruptive. Therefore, in our experiment, we could predict interference effects for slower responses. For the Simon effect, the findings are less clear. One the one hand, it has been shown that this effect can decrease with increasing response latency (De Jong et al., 1994; Hommel, 1994; Wiegand, & Wascher, 2005). On the other hand, for more complicated mappings, it has been proven to increase with increasing response latency (Wascher et al., 2001; Wiegand, & Wascher, 2005). Van Zoest et al. (2012) provided another example for the effects of time-course by asking participants to respond to the presence (with their right index finger) or absence (with their left index finger) of a singleton arrow. The direction of the arrow could be corresponding or not corresponding with the response if it pointed to the right or not corresponding with the response if it pointed to the left. Van Zoest et al. (2012) found that the direction of the arrow only had effects when participants were actively encouraged to process the identity of the arrow and SRC effects increased over response time.

1.4 Reaching trajectories

Reaching trajectories are another important method used in this thesis. Recent work by Song and colleagues has shown that they give more insight into the time-course of visual attention than simple RT tasks (e.g. Moher et al., 2015; Song, 2017; 2019). . For example, it is a common finding that when the distractor can be a potential target, then reaching is first initiated towards the distractor before it is corrected towards the target, which is represented in curved trajectories (e.g. Song, & Nakayama, 2008; Welsh, & Elliott, 2005).

The choice reaching task (CRT; Song, & Nakayama, 2008; 2009) allows to measure two components of the time-course of hand movements:

1) Initiation latency (IL): the time it takes to start the movement, and
2) Maximum deviation (MD): the curvature of the movement until the final target is reached.

Importantly, reaching trajectories can offer insight into cognitive processes that simple RT tasks cannot provide.

The time course of reaching trajectories in automatic interference effects was also examined. Buetti and Kerzel (2008) tested the characteristics of the Simon effect by measuring RTs and initial movement angles (IMAs). Small IMAs reflect a direct movement to the instructed location, whilst large IMAs reflect an initially wrong movement towards the wrong location in the Simon task (curved trajectories in Song and Nakayama’s, 2008, terminology). IMAs were analysed accorded to the time-course (from fastest to slowest responses) and the authors found that the Simon effect decreased with increasing RTs. In contrast to the RT studies mentioned in section 3.4, in reaching trajectories there was therefore no increase in the Simon effect with increasing RTs, showing that reaching trajectories can provide additional insight that simple RT studies cannot offer.

Priming effects were also tested in studies measuring reaching trajectories. Finkbeiner et al. (2008) studied pointing trajectories by using primes that were congruent (valid) or incongruent (invalid) with the target participants had to point to. They found that pointing trajectories were greater following incongruent (invalid) primes than after congruent (valid) primes. Friedman and Finkbeiner (2010) provided additional evidence for the time-course of reaching trajectories in congruent vs. incongruent priming by finding that fewer submovements (following the assumption that reaching trajectories are made up of submovements) were needed for congruent trials and by finding that the interference effect on the number of submovements was larger for repeated primes compared to novel primes. According to the authors, this finding could not have been shown in RTs before, suggesting that analysing the time-course of reaching trajectories provides additional evidence that cannot be found with simple RT tasks. Bundt et al. (2018) showed that the Stroop effect in a mouse-tracking task was larger when there were 80% congruent trials, compared to the condition with 20% congruent trials, which they explained with item-specific cognitive control. The Stroop effect was reflected in faster and more accurate movement times for congruent trials. Importantly, this study also provided evidence for the time-course of reaching trajectories, as for relatively fast responses, this effect could only be observed for movement times, whilst for relatively slow responses, this effect was found in both the initiation of the movement and movement times. This provides again evidence for the benefits of measuring the time-course of visual attention with reaching trajectories. If a simple RT task had been chosen, no effects for fast responses might have been found.

Concerning global and local processing, there is only one known study that investigated whether those processes are also reflected in hand movements. McCarthy and Song (2016) found that reaches were initiated faster when a task-irrelevant illusionary global figure present. They used local Pac-men that formed congruent or incongruent Kanizsa triangles. However, the task-irrelevant illusionary global figure had no effects on MD. Additionally, RTs were faster and movement curvatures were reduced when target colours repeated, independent of whether global figure present or not. This is termed as priming of pop-out. As mentioned in section 1.2.1, it is generally assumed that responses to global elements are faster than responses to local elements (e.g. Martin, 1979; Navon, 1981; Heinze, & Münte, 1993). This global-to-local processing was specified in the reverse hierarchy theory (RHT; Hochstein, & Ahisser, 2002). Combining the CRT with the RHT, it can be assumed that global processing might be reflected in IL (the start of the movement) and local processing in MD, which follows afterwards. This thesis aimed to find out whether local processing is reflected in MD. This was examined by again using Navon stimuli and rendering them task-irrelevant by asking participants to just reach to the location of a dot embedded in one of the local letters (chapter 6). Consistent with the hypotheses made for RTs, it was hypothesised that MD should be greater for incongruent conditions.

1.5 Conclusion and outline of the thesis

It can be concluded that irrelevant visual information processing and its subsequent interference effects are an important aspect of visual attention. This thesis will focus on irrelevant visual information processing and the possible occurrence of task-irrelevant interference effects. This will be done by rendering the Navon letter identity irrelevant and designing a relevant task, which will be responding to the luminance of the letters. It was hypothesised that the letters would still be processed by the participants, based on Gestalt experiments that showed that grouping of local parts as well as interference effects can occur without participants' attention (Kimchi et al., 2018; Montoro et al., 2014; Moore, & Egeth, 1997; Rashal et al., 2017). The Stroop task (Stroop, 1935) provides another rationale for the occurrence of task-irrelevant processing, specifically letter processing. Task-irrelevant interference effects will be examined depending on whether participants' attention is directed to the global or to the local level.

A further aim of this thesis is to test the specific time-course of those hypothesised interference effects. Here, it is important to note that time-course can be manipulated between different experiments, based on luminance manipulation. Time-course can also be assessed within each individual experiment, based on the different conditions (bright and dark letters or dots, different letters). Within an experiment, time-course can be assessed using population means (chapters 2-4) or using quantiles (chapter 5). Finally, time-course of task-irrelevant interference effects will be assessed in this thesis by using the CRT (chapter 6).

In this thesis, it was manipulated whether participants' attention was directed to the global or to the local level with the aim to test for the occurrence of task-irrelevant interference effects in Navon stimuli. In chapter 2, participants' attention was directed to the global level by asking them to respond to the luminance of a letter (congruent or incongruent) that was embedded in a square. In contrast, in chapters 3 and 4, participants' attention was directed to the local level by asking them to respond to the luminance of a dot that was embedded in one of the local letters of the Navon stimuli. Again, the global and local letters were either congruent or incongruent. Whilst in chapters 2-4, the analysis will be done based on the different global and local letters and luminance levels, in chapter 5, the analysis will be averaged across the different letters in order to find out whether the interference effect is independent of letters. In addition, in chapter 6, task-irrelevant interference effects on the local level will be analysed by measuring reaching trajectories. The thesis concludes with a general discussion and implications of the findings of the experimental chapters (chapter 7).

Chapter Two: GLOBAL LETTER LUMINANCE EXPERIMENTS

2.1 Introduction

The aim of this chapter is to establish how task-irrelevant visual information is processed and to find out if interference effects occur in stimuli that are not relevant to the task. This question was examined by using the Navon task, because the usage of these stimuli enables to get insight into the occurrence of task-irrelevant interference effects depending on whether attention is directed to the global or to the local level. In contrast, other experiments that examined task-irrelevant visual processing, such as the Stroop task (Stroop, 1935) or the Eriksen flanker task (Eriksen, & Eriksen, 1974), cannot manipulate global and local level focus of attention.

In order to render the responses to the Navon letters irrelevant and to create a relevant task, participants were asked to respond whether a letter embedded in a square (global H or I, congruent or incongruent) was either brighter or darker than the square (figure 7). It was predicted that responses to matching (congruent) conditions would still be faster (figure 4), as found in experiments using the classic Navon paradigm (e.g. Hoffmann, 1980; Martin, 1979; Navon, 1977; 1981), because it was hypothesised that despite being task-irrelevant, the letter identity would still be processed. This prediction was made based on the literature about Gestalt grouping. One of the most important principles of Gestalt grouping is that local parts can be grouped to a global whole if certain conditions such as proximity or connectedness are met (Rock, & Palmer, 1990), therefore Navon stimuli are one example for Gestalt grouping (Han et al., 1999). It has been shown that grouping of stimuli and interference effects can occur without attention, meaning that the shape of the stimuli is processed automatically (Kimchi et al., 2018; Montoro et al., 2014; Moore, & Egeth, 1997; Rashal et al., 2017). However, those experiments did not investigate automatic processing of task-irrelevant letters. Therefore, the Stroop effect (Stroop, 1935) served as another rationale for the prediction of automatic processing of stimuli, specifically task-irrelevant letters. Nevertheless, the differences between the Stroop task and our series of experiments have to be pointed out. In the Stroop task, interference effects occur between the relevant and the irrelevant stimulus dimension, whilst in our task, it is aimed to test for the interference effects between the two irrelevant stimulus dimensions of letter identity. In addition, in the Stroop task, task-irrelevant words are processed, whilst our series of experiments did investigate task-irrelevant letters. However, it was assumed that if task-irrelevant words are processed in the Stroop task, the same effect might occur for task-irrelevant letters. The literature about stimulus-stimulus-compatibility (SSC) and stimulus response-compatibility (SRC, Kornblum, 1992) provides additional support for the assumption that letter identity would still be processed despite being task-irrelevant. According to Kornblum's (1992) model, the occurrence of compatibility effects has been explained by the dimensional overlap between two stimulus dimensions (SSC) or the overlap of a stimulus and a response (SRC). Famous examples for SSC are the Stroop task (Stroop, 1935) and the Navon task (Navon, 1981), whilst one famous example for SRC is the Eriksen flanker task (Eriksen, & Eriksen, 1974). One important prediction of SSC and SRC is that compatibility effects can occur if one or both stimulus dimension are irrelevant (Kornblum, 1992), as it is the case in our series of experiments.

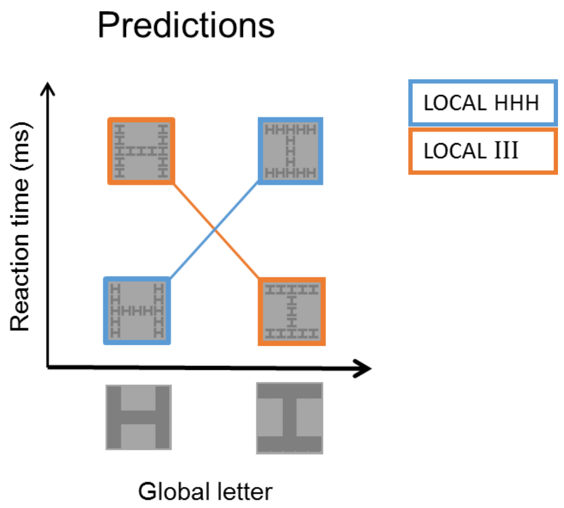


Figure 4: Predictions of interference effects
Predictions about the occurrence of interference effects with our stimuli.

There is evidence that interference effects are affected by the time-course of responses and that the occurrence of interference effects might depend on fast vs. slow responses. Our series of experiments consisted of different versions of luminance contrast (from highest to lowest, figure 7) to find out whether this would influence the occurrence of interference effects. It has been shown that high luminance contrast generally leads to short RTs (Plainis, & Murray, 2000; Walkey et al., 2006). Therefore, the aim was of manipulating luminance contrast was to manipulate speed of responding, which should provide insight into the time-course of interference effects between experiments. Within experiments, it was aimed to manipulate time-course by asking participants to either respond to dark letters or to bright letters, as dark stimuli have been shown to be processed faster than bright stimuli (e.g. Buchner, & Baumgartner, 2007; Komban et al., 2001).

Two different predictions were made about this hypothesised time-course of the hypothesised interference effects. On the one hand, cognitive control could serve as one explanation. Research has shown that automatic processes can be described as rather fast and controlled processes can be described as rather slow and at the same time, efficient cognitive control has been linked to reduced interference effects (Bialystok et al., 2004; Coderre, & van Heuven, 2014; Jansma et al., 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984; Shiffrin, & Schneider, 1977; Stuss et al., 2001; White et al., 2018). Therefore, we could assume efficient cognitive control mechanisms for slow responses and this might in turn reduce interference effects. This prediction was made for both within experiments and between experiments.

The bottleneck theory (Appelbaum et al., 2012; Broadbent, 1958; Dyer, 1971; Glaser, & Glaser, 1982; Lu, & Proctor, 2001; Roelofs, 2010; Starrevald, & La Heij, 2017) serves as another prediction for faster responses to matching conditions, if luminance detection and letter identification are seen as two independent processes. If responses to mismatching conditions were slower, this would mean that both processes would finish at a similar time, hereby causing a bottleneck, which in turn leads to interference. The time-course predictions for the occurrence of interference effects between experiments according to the bottleneck theory are different from the time-course predictions of interference effects according to the cognitive control theory, as the bottleneck theory predicts a kind of reverse U-shaped relationship between incongruent (mismatching) stimuli and luminance contrast. This means that neither high nor low luminance contrast would lead to interference effects, when responses are generally fast or slow (Pashler, & Johnston, 1988). Within experiments, no specific time-course prediction of interference effects was made.

It has however need to be made clear that it is also possible that task-irrelevant interference effects would not occur, given that participants' task was just to respond to the luminance, so they might not process the task-irrelevant letter. Additionally, even if task-irrelevant interference effects occurred, it is possible that time-course would not influence interference, hereby not supporting any of the three different predictions about the time-course. First of all, we conducted the standard Navon experiment with the aim to establish whether our stimuli produce the standard effect of slower responses to incongruent conditions.

2.2 Experiment 1: Navon task using the stimuli H and I

The aim of this experiment was to test whether the compound stimuli that we used (congruent and incongruent letters H and I) elicit the global precedence effect. Given the findings in the literature about Navon stimuli, the global precedence effect does not always occur (e.g. Grice et al., 1983; Heinze, & Münte, 1993; Hoffmann, 1980; Martin, 1979; see Kimchi, 1992, for a critical review). In this experiment, the terminology congruent vs. incongruent conditions was chosen instead of matching vs. mismatching conditions, because the letters were task-relevant. The different letters H and I were analysed separately in order to find out whether they would lead to consistent effects.

2.2.1 Methods

Participants

29 students from the University of Birmingham took part in the experiment in exchange for course credits or monetary compensation. The inclusion criteria were normal or corrected-to-normal vision and normal colour vision. The mean (M) age was 20.90 years (standard deviation, SD: 3.11), 13 participants were female, and 24 participants were right-handed.

Stimuli

A big global letter that was an H or an I (7.6°) and that was made out of smaller local letters, again H or I (1.5°), was presented in the centre of the computer screen. The letters contained a dot that was irrelevant to this experiment. The letters were grey (Red Green Blue, RGB values: 149[1]) and they were presented against a white background. If the big letter was made out of the same smaller letters (e.g. an H made out of Hs), the letters were congruent and if the big letter was made out of different small letters (e.g. an H made out of Is), the letters were incongruent (figure 5).

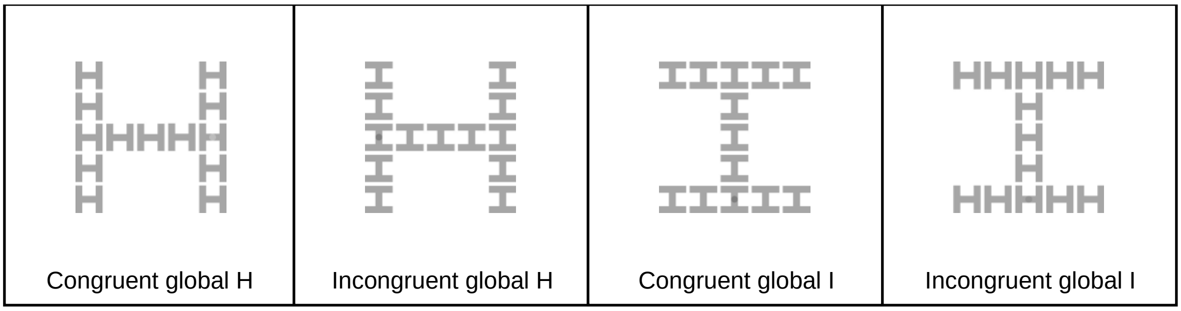


Figure 5: Stimuli in the replication of the Navon experiment

Procedure

Participants were seated 45 centimetres (cm) in front of a computer screen in a darkened room. Before every trial, a black fixation cross (0.9°) appeared in the centre of a black screen. After 2000 ms, the global letter made out of local letters was presented on the screen. Participants were asked to press the corresponding keys according to the letter identity either on the global or on the local level (m for I and k for H) on the computer keyboard. The letter remained on the computer screen until participants made a response. Participants were asked to respond to the same target level (global or local) throughout the whole block and in the following block, the response required to the target level changed. The order of the target levels (first global, then local or vice versa) was balanced across participants.

[1] It is important to note that those values are monitor-dependent and therefore do not reflect the true values.

Design

The experiment consisted of 6 blocks with 96 trials each. Before the start of the experiment, participants completed 7 practice trials. In each block, the number of congruent and incongruent conditions and of the two different global letters was balanced.

Analysis

A three-way repeated measures analysis of variance (ANOVA) with the factors interference (congruent vs. incongruent conditions), letter (global H vs. global I) and target level (global vs. level) was conducted on RTs (in seconds, s) and accuracy. The exclusion criteria of participants was accuracy lower than 95%. 8 participants had to be excluded from the analysis according to this criterion. Outlier removal of trials was based on RTs higher or lower than 2 SD above or below the mean RT. This means that all trials with RTs higher than 1.32 s and lower than 0.35 s were excluded from the analysis.

2.2.2 Results

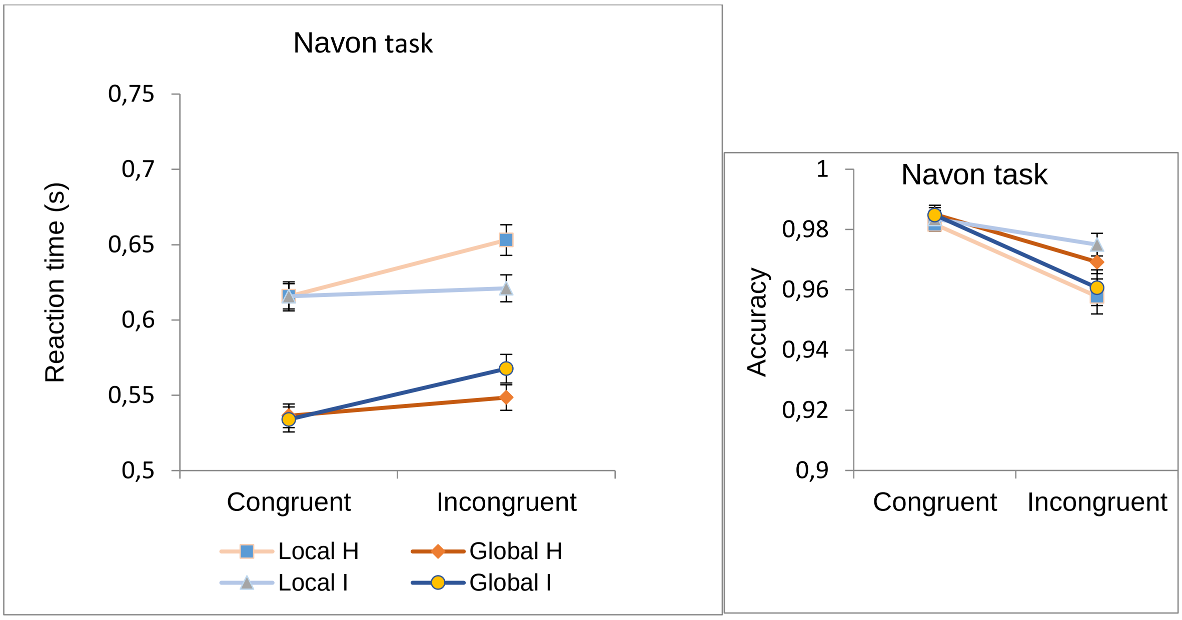


Figure 6: Results of the replication of the Navon experiments
Experiment 1: Participants were instructed to respond to the identity of the letter either on the global or on the local level. They responded faster to congruent conditions (thus when global and local letters matched) and when making responses on the global level. However, for the letter I, they only responded on the global level faster to congruent conditions. Participants were more accurate for congruent conditions. There was no speed-accuracy trade-off. [2]

Reaction times

There was a significant main effect of interference, $F(1,20)=23.705$, $p<.001$, $\eta^2_p=.542$. Participants responded faster to congruent (M:0.575, SD:0.101) than to incongruent conditions (M:0.598, SD:0.101). There was also a significant main effect of target level, $F(1,20)=25.378$, $p<.001$, $\eta^2_p=.559$, with participants responding faster on the global (M:0.547, SD:0.101) than on the local level (M:0.626, SD:0.101). The interactions letter x target level, $F(1,20)=14.472$, $p=.001$, $\eta^2_p=.420$, and interference x letter x target level, $F(1,20)=10.144$, $p=.005$, $\eta^2_p=.337$, were significant as well. The main effect of letter was not significant, $F(1,20)=.660$, $p=.426$, $\eta^2_p=.032$, and all other interactions were not significant either. To further examine the significant interactions, simple effect analyses were conducted on both letters H and I separately.

[2] The error bars in all figures in this thesis represent the standard error.

For global H, the main effect of interference was significant, $F(1,20)=9.527$, $p=.006$, $\eta^2_p=.323$. Participants responded faster to congruent (M:0.576, SD:0.096) than to incongruent conditions (M:0.601, SD:0.101). There was also a significant main effect of target level, $F(1,20)=32.048$, $p<.001$, $\eta^2_p=.616$, with participants responding faster on the global (M:0.542, SD:0.092) than on the local level (M:0.634, SD:0.110). Finally, the interaction interference x target level was significant as well, $F(1,20)=5.737$, $p=.026$, $\eta^2_p=.224$. To further examine this interaction, a t-test was carried out on congruent vs. incongruent conditions for global vs. local conditions separately. There was a significant interference effect on the local level, $t(20)=-3.049$. Participants responded faster to congruent M:0.616, SD:0.111) than to incongruent conditions (M:0.653, SD:0.118). The interference effect on the global level was nearly significant, $t(20)= -2.086$, $p=.050$. Again, participants responded faster to congruent (M:0.535, SD:0.093) than to incongruent conditions (M:0.548, SD:0.096).

For global I, there was a significant main effect of interference, $F(1,20)=9.027$, $p=.007$, $\eta^2_p=.311$. Participants responded faster to congruent (M:0.575, SD:0.110) than to incongruent conditions (M:0.594, SD:0.101). There was also a significant main effect of target level, $F(1,20)=17.691$, $p<.001$, $\eta^2_p=.469$. Participants responded faster on the global (M:0.551, SD:0.110) than on the local level (M:0.618, SD:0.110). Finally, the interaction interference x target level was significant, $F(1,20)=6.253$, $p=.021$, $\eta^2_p=.238$. To further examine this interaction, a t-test was carried out on congruent vs. incongruent conditions for global vs. local conditions separately. It was only significant on the global level, $t(20)= -4.198$, $p<.001$. Participants responded faster to congruent (M:0.534, SD:0.104) than to incongruent conditions (M:0.568, SD:0.102). On the local level, there was no significant interference effect, $t(20)= -.578$, $p=.570$.

Accuracy

There was a significant main effect of interference, $F(1,20)=64.102$, $p<.001$, $\eta^2_p=.762$. Participants were more accurate for congruent (M:0.984, SD:0.014) than for incongruent conditions (M:0.966, SD:0.014). The interaction letter x target level was significant as well, $F(1,20)=6.478$, $p=.019$, $\eta^2_p=.245$. The main effects of letter, $F(1,20)=.809$, $p=.379$, $\eta^2_p=.039$, and of target level, $F(1,20)=.018$, $p=.893$, $\eta^2_p=.001$, were not significant. All other interactions were not significant either. To further examine the interaction between letter and target level, simple effect analyses were conducted on both letters H and I separately.

For global H, the main effect of interference was significant, $F(1,20)=22.582$, $p<.001$, $\eta^2_p=.530$. Participants were more accurate for congruent (M:0.983, SD:0.014) than for incongruent conditions (M:0.963, SD:0.019). The main effect of target level, $F(1,20)=3.929$, $p=.061$, $\eta^2_p=.164$, and the interaction were not significant.

For global I, the main effect of interference was significant as well, $F(1,20)=14.810$, $p=.001$, $\eta^2_p=.425$. Again, participants were more accurate for congruent (M:0.984, SD:0.014) than for incongruent conditions (M:0.968, SD:0.019). The main effect of target level, $F(1,20)=1.967$, $p=.176$, $\eta^2_p=.090$, and the interaction were not significant. Hence, overall, there was no speed-accuracy trade-off.

2.2.3 Discussion

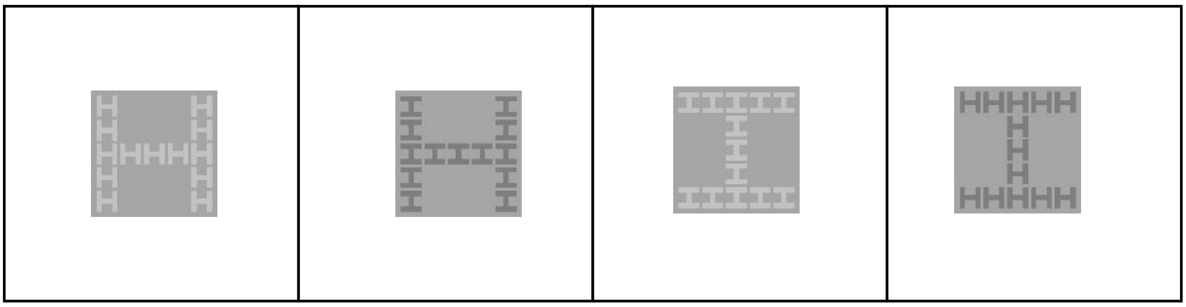
In this experiment, participants responded to the identity of the letter either on the global or on the local level. Two major findings from previous studies using similar stimuli were replicated: participants responded faster when stimuli were congruent and they responded faster when making responses on the global level (e.g. Navon, 1977; 1981). However, in this experiment, the strength of the interference effect depended on the identity of the letter. When the global letter was an H, the interference effect occurred on both levels, global and local, whereas when the global letter was an I, the interference effect only occurred on the global level. This is in contrast to global precedence that suggests interference effects on the local level (e.g. Navon, 1977. 1981) and supports the local precedence theory (e.g. Hoffmann, 1980; Martin, 1979). Looking at Gestalt grouping principles, especially into grouping by similarity (e.g. Rock, & Palmer, 1990) and considering that Navon stimuli are one example for Gestalt grouping (Han et al., 1999), it is possible that grouping on the local level occurred for the letter H but not for I. This led to an interference effect for the letter H on the local level. However, it remains unclear why grouping of local stimuli occurred for a global H but not for a global I. One possible explanation could be that the grouping was not based on similarity, as both letters H and I are very similar. Therefore, it is possible that the differences between global H and I occurred based on typicality of letters. Research has shown that performance is generally better for typical targets (e.g. Maxfield et al., 2014; Rosch et al., 1976) and the letter H used in this experiment can be seen as a more typical representative than the letter I. Therefore, local Is might not have been grouped. Nevertheless, both letters H and I can be seen as sufficient to cause interference effects and to cause shorter RTs on the global level, therefore they were used in the next experiment.

2.3 Global letter luminance experiments

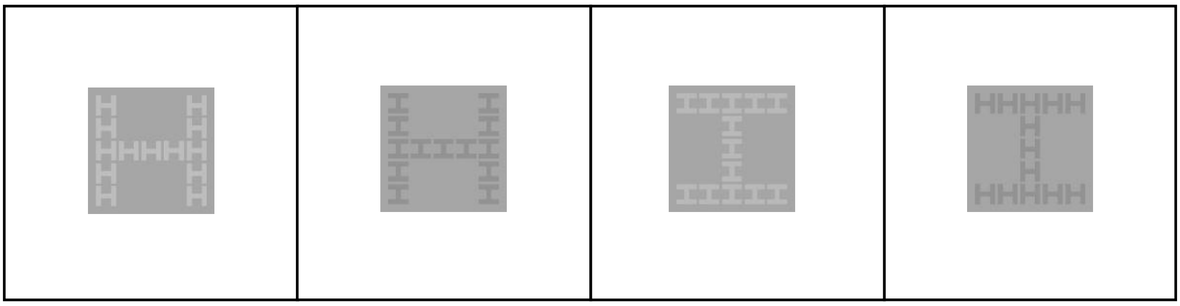
The motivation for this series of experiments was to find out whether matching (congruent) letter identity still leads to shorter RTs and mismatching (incongruent) conditions cause longer RTs even if letter identity is task-irrelevant. The prediction was that there would be an interaction of global letter and local letter, with faster responses to matching conditions. As both letter identities were task-irrelevant, the terminology of matching and mismatching rather than congruent and incongruent conditions was used. However, when referring to the literature in the discussion of those effects, it is not always possible to make a clear distinction between the terms. Therefore, sometimes the wording matching vs. mismatching and sometimes the wording congruent vs. incongruent will be used in this thesis. Because the relevant task (luminance decision) is irrelevant of letter identity, the analysis was done based on the different letters in order to find out whether different letter identity would drive the effects. A further motivation to split up the analysis into different letters was that differences between the letters were shown in the classic Navon experiment (experiment 1). The analysis was also split in bright vs. dark letters, considering that dark stimuli are usually processed faster and more accurately (Buchner, & Baumgartner, 2007; Komban et al., 2001). The luminance contrast ranged from highest to lowest contrast to test the possible time-course effects of interference, especially the predicted reversed U-shape function of the bottleneck theory (Pashler, & Johnston, 1988).

Global letter luminance experiments

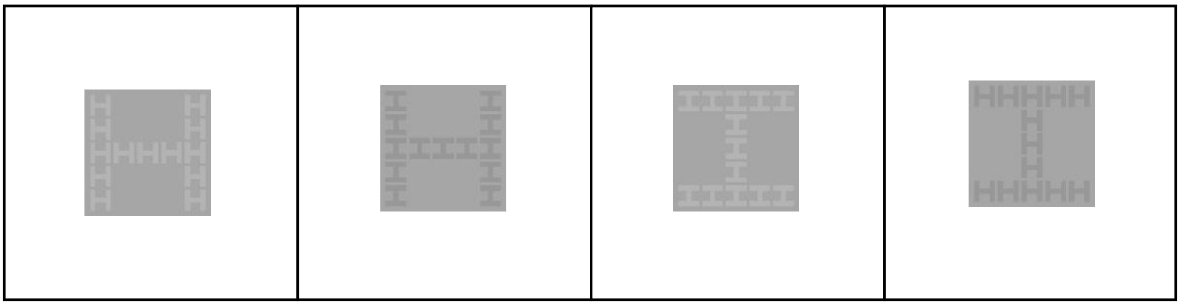
Stimuli for experiment 2



Stimuli for experiment 3



Stimuli for experiment 4



Stimuli for experiment 5

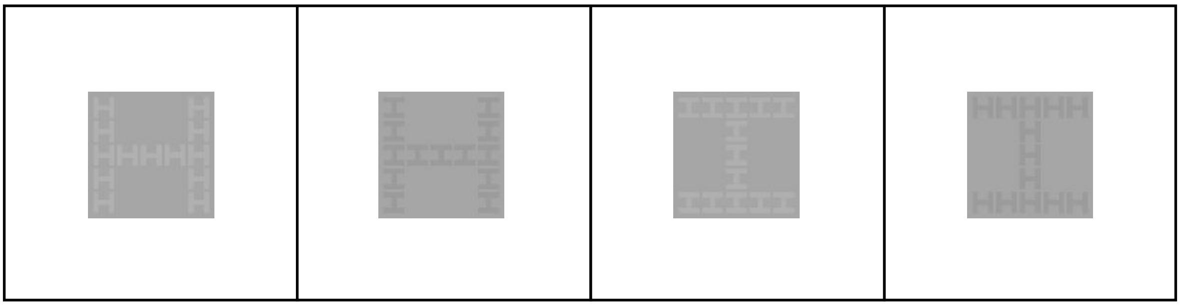


Figure 7: Stimuli of the global level condition
Experiments 2-5: Highest to lowest luminance contrast. The most left image contains a bright global H with local Hs, which means that the global and local level match. The second image is a dark global H with local Is, which means that the global and local level do not match. The third image represents a bright global I, which consist of locals Is, thus the global and local level match. The most right image is a dark global I with local Hs, which means that here the global and local level do not match.

2.3.1 Experiment 2: Highest luminance contrast

2.3.1.1 Methods

Participants

27 students from the University of Birmingham took part in the experiment in exchange for course credits or monetary compensation. The inclusion criteria were normal or corrected-to-normal vision and normal colour vision. The mean age was 19.52 years (SD: 1.78), 19 participants were female, and 22 participants were right-handed.

Stimuli

A big global letter that was an H or an I (7.6°) and that was made out of smaller local letters, again H or I (1.5°), was presented in the centre of the computer screen. The letters were embedded in a grey square (7.9°, RGB values: 149) that was presented on a white background. If the big letter was made out of the same smaller letters (e.g. an H made out of Hs), the letters matched and if the big letter was made out of different small letters (e.g. an H made out of Is), the letters did not match. The letters were either brighter (RGB values: 182) or darker (RGB values: 108) than the surrounding square (figure 7).

Procedure

Participants were seated around 45 cm in front of a computer screen in a darkened room. Before every trial, a black fixation cross (0.9°) appeared in the centre of a black screen. After 2000 ms, the global letter made out of smaller local letters was presented on the screen. Participants were asked to press the corresponding keys according to the letter brightness (m for dark and k for bright) on the computer keyboard. The letter remained on the computer screen until participants made a response.

Design

The experiment consisted of 6 blocks with 96 trials each. Before the start of the experiment, participants completed 12 practice trials. In each block, the number of matching and mismatching conditions and of the two different global letters was balanced. Half of the trials contained bright letters and the other half contained dark letters.

Analysis

A three-way repeated-measures ANOVA with the factors global letter (H vs. I), local letter (H vs. global I) and luminance (bright or dark) was conducted on RTs (in s) and accuracy. The exclusion criterion of participants was accuracy lower than 90%. 1 participant had to be excluded from the analysis according to this criterion. Outlier removal of trials was based on RTs higher or lower than 2 SD above or below the mean RT. This means that all trials with RTs higher than 1.28 s were excluded from the analysis.

2.3.1.2 Results

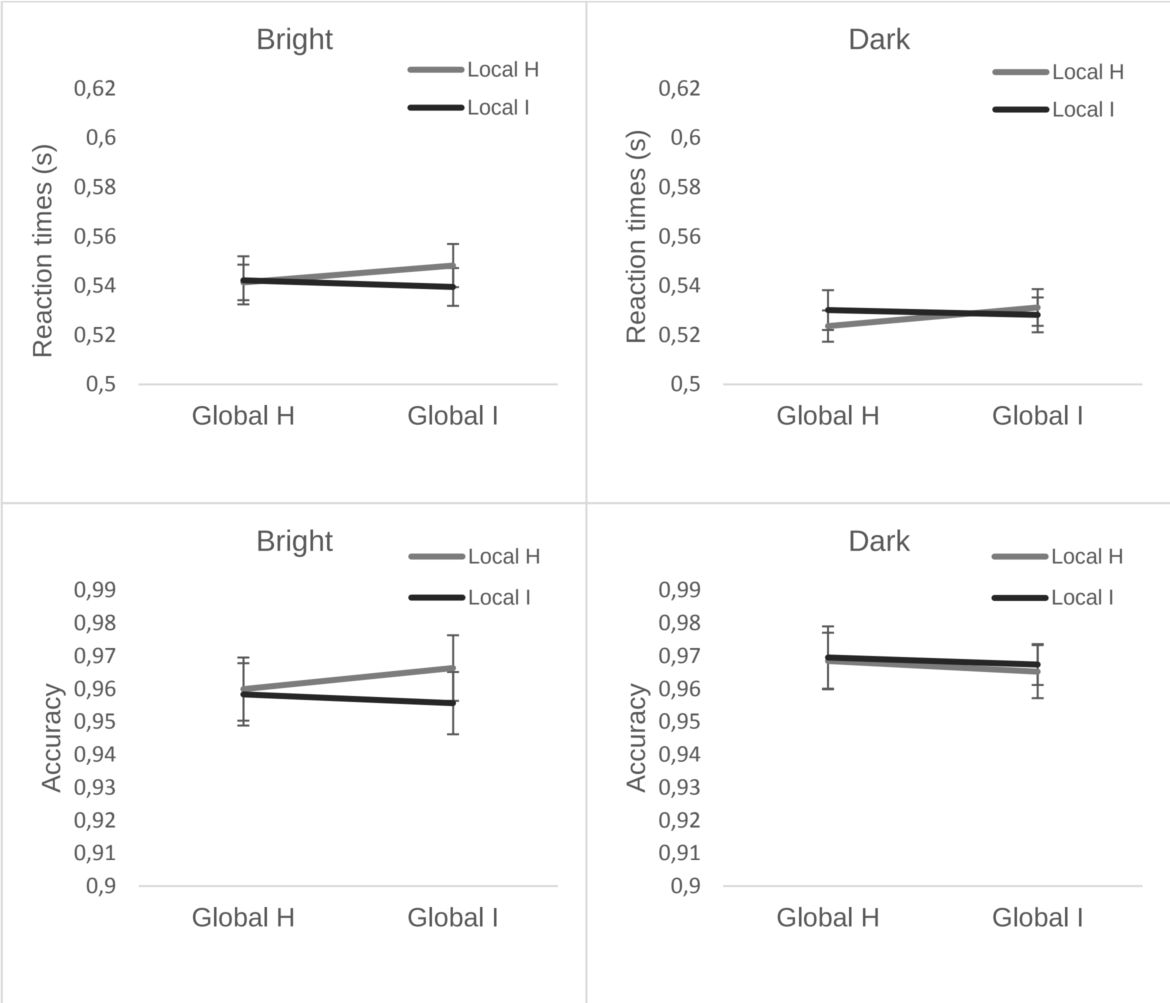


Figure 8: Results of the highest luminance experiment (global level)
Experiment 2: Participants responded faster when the letters were dark. There were no significant effects for accuracy and therefore there was no speed-accuracy trade-off.

Reaction times

There was a significant main effect of luminance, $F(1,25)=6.865$, $p=.015$, $\eta^2_p=.215$. Participants responded faster when the letters were dark (M:0.528, SD:0.071) than when they were bright (M: 0.543, SD:0.076). The main effects of global letter, $F(1,25)=1.007$, $p=.325$, $\eta^2_p=.039$, and local letter, $F(1,25)=.185$, $p=.325$, $\eta^2_p=.007$, were not significant. None of the interactions were significant.

Accuracy

There were no significant effects.

2.3.1.3 Discussion

The results did not show any interaction between the global letters and the local letters. In other words, whether the local and global letter were the same or not, did not reliably impact RTs. Our hypothesis that matching or mismatching conditions should affect responses although participants are not asked to respond to the letter itself could not be confirmed. Only the main effect of luminance was significant, with participants responding faster to dark than to bright letters. This result probably occurred due to the fact that the grey square, in which the letter was embedded, was presented on a white background, which led to a larger overall luminance contrast when the letter was dark, thereby leading to faster detection. This also replicates the findings of Buchner and Baumgartner (2007) and Komban et al. (2001). In this experiment, the luminance contrast between the letters was relatively large and RTs were relatively short, replicating findings by Plainis and Murray, 2000, and Walkey et al., 2006. In this experiment, RTs were also shorter than in the previous standard Navon task experiment.

The failure to find an interference effect can be explained in line with the bottleneck theory, which suggests interference if two competing processes are happening simultaneously (Appelbaum et al., 2012; Broadbent, 1958; Dyer, 1971; Glaser, & Glaser, 1982; Lu, & Proctor, 2001; Roelofs, 2010; Starrevald, & La Heij, 2017). Hence, it is possible that in this experiment luminance detection was completed before the letters were processed, therefore the two processes did not interfere. Therefore, bringing the two processes closer together in time might increase the likelihood of finding interference effects.

It is worth noting that the failure of finding an interference effect can be also explained with the cognitive control theory, which assumes that controlled processes are slower than automatic processes and that efficient cognitive control reduces interference effects (Bialystok et al., 2004; Coderre, & van Heuven, 2014; Jansma et al., 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984; Shiffrin, & Schneider, 1977; Stuss et al., 2001; White et al., 2018). It is possible that RTs in this experiment were shorter than they would be in experiments with less luminance contrast between dark and bright dots and therefore in this experiment automatic instead of controlled processing might have taken place throughout the whole experiment. Consequently, it would not have been possible to distinguish between automatic and controlled processes within this experiment. It is possible that responses have to be overall slower in order to be able to distinguish between automatic and controlled processing within one experiment. Hence, both explanations, the bottleneck theory and the cognitive control theory, suggest that response latency was too short in this experiment. Therefore, another experiment with less luminance contrast was carried out.

2.3.2 Experiment 3: Second-highest luminance contrast

In experiment 2, no interference effects occurred at all. One possible explanation could be that the luminance contrast between bright and dark letters was too high and therefore responses throughout the whole experiment were so fast that the letters were not processed at all. In order to test this interpretation, a second experiment with less luminance contrast between the letters was carried out. It was predicted that this would slow down responses, leading to increased cognitive control. This might lead to interference effects for conditions with generally fast responses but reduced interference effects for conditions with slow responses within this experiment (Bialystok et al., 2004; Coderre, & van Heuven, 2014; Jansma et al., 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984; Shiffrin, & Schneider, 1977; Stuss et al., 2001; White et al., 2018). In line with the bottleneck theory, it was predicted that the two processes of letter identification and luminance response could be brought closer together in time, which in turn should lead to interference effects (Appelbaum et al., 2012; Broadbent, 1958; Dyer, 1971; Glaser, & Glaser, 1982; Lu, & Proctor, 2001; Roelofs, 2010; Starrevald, & La Heij, 2017).

2.3.2.1 Methods

Participants

24 students from the University of Birmingham took part in the experiment in exchange for course credits or monetary compensation. The inclusion criteria were normal or corrected-to-normal vision and normal colour vision. The mean age was 19.12 years (SD: 0.76), 17 participants were female, and 22 participants were right-handed.

Stimuli, Procedure, Design and Analysis

The experimental stimuli, procedure, design and analysis were the same as in experiment 2, apart from that this time, the luminance level between bright (RGB values: 176) and dark letters (RGB values: 129) was reduced. The exclusion criterion was again accuracy lower than 90%. According to this criterion, no participants had to be excluded from the analysis. Outlier removal was based on the same criteria as before and according to this, all trials with RTs higher than 1.53 s were excluded from the analysis.

2.3.2.2 Results

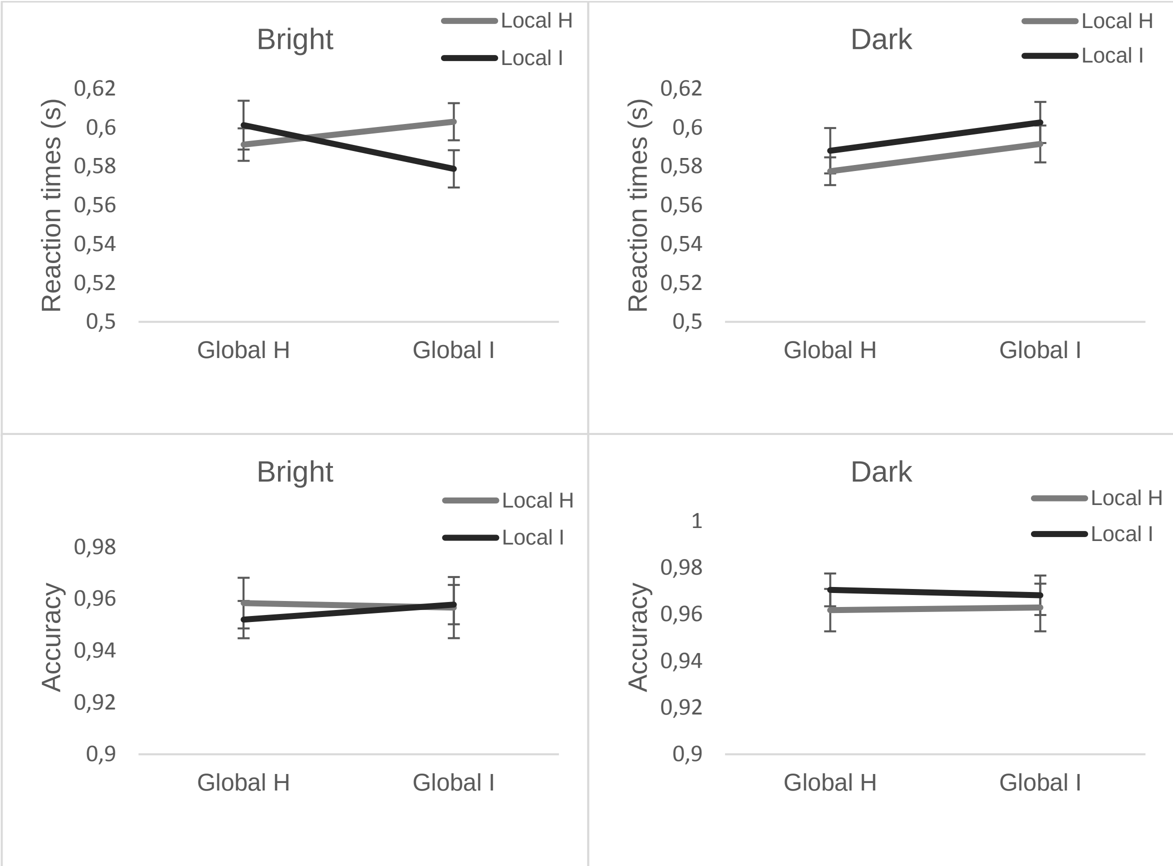


Figure 9: Results of the second-highest luminance experiment (global level)
Experiment 3: Participants responded faster if the global H consisted of local Hs. Participants also responded faster if the global I consisted of local Is, but only if the letters were bright. Participants were more accurate for dark letters, so there was no speed-accuracy trade-off.

Reaction times

There was no significant main effect of luminance, $F(1,23)=.296$, $p=.591$, $\eta^2_p=.013$. The main effects of global letter, $F(1,23)=1.594$, $p=.219$, $\eta^2_p=.065$, and of local letter, $F(1,23)=.464$, $p=.502$, $\eta^2_p=.020$, were not significant either. The interaction luminance x global letter, $F(1,23)=11.358$, $p=.003$, $\eta^2_p=.331$, was significant, as well as the interaction luminance x local letter, $F(1,23)=7.802$, $p=.010$, $\eta^2_p=.253$. The interaction global letter x local letter, $F(1,23)=4.785$, $p=.039$, $\eta^2_p=.172$, was also significant. Finally, the interaction luminance x global letter x local letter, $F(1,23)=11.256$, $p=.003$, $\eta^2_p=.329$, was significant. To further examine the significant interactions, simple effect analyses were conducted on both global H and I separately.

For global H, there was a significant main effect of local letter, F(1,23)=1,23)=5.360, p=.030, η^2_p=.189. Participants responded faster when the local letter was an H (M:0.584, SD:0.103) than when it was an I (M:0.595, SD:0.103). The main effect of luminance was not significant, F(1,23)=3.367, p=.079, η^2_p=.128. The interaction was not significant either.

For global I, there were no significant main effects of local letter, F(1,23)=1.774, p=.196, η^2_p=.072, nor of luminance, F(1,23)=.754, p=.394, η^2_p=.032., but a significant interaction interference x luminance, F(1,23)=26.330, p<.001, η^2_p=.534. To further examine this interaction, a t-test was conducted on local H vs. local I for both bright and dark global I separately. There was a significant effect of local letter for bright letters, t(23)= -3.805, p=.001. Participants responded faster to a local I (M: 0.579, SD: 0.098) than to a local H (M: 0.603, SD: 0.099). For dark I, there was no significant effect of local letter, t(23)=1.950, p=.064.

Accuracy

There was a significant main effect of luminance, F(1,23)=4.431, p=.046, η^2_p=.162. Participants were more accurate for dark (M:0.966, SD:0.029) than for bright letters (M:0.956, SD:0.034). As there was no significant effect of luminance on RTs, there was no speed-accuracy trade-off. The main effects of global letter, F(1,23)=.044, p=.836, η^2_p=.002**,** and of local letter, F(1,23)=.427, p=.520, η^2_p=.018, were not significant. All the interactions were not significant either.

2.3.2.3 Discussion

In contrast to experiment 2, the results of this experiment showed the expected interference effect. However, this effect was only independent of the luminance level for the letter H. For the letter I, matching conditions only led for bright letters to faster responses. At the same time, participants seemed to respond faster to a bright I than to a dark I. Although this luminance effect was not significant, it suggests that compatibility between the local and the global letter only leads to short RTs if responses within an experiment trend to be fast. This interpretation can be confirmed by the fact that RTs to H were shorter than RTs to I, although it is important to mention again that this effect was not significant. The differences in interference effects for certain conditions can be explained both with the cognitive control theory and the bottleneck theory. However, it has to be noted that those explanations have to be considered with caution, because the differences in RTs for conditions with rather fast or slow responses within this experiment were not significant. Cognitive control has been linked to longer RTs (Jansma et al., 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984; Shiffrin, & Schneider, 1977). Therefore, we can assume efficient cognitive control for long RTs within an experiment, which therefore diminished the interference effect.

In addition, the results of this experiment support the bottleneck theory. For the previous experiment, this theory suggested that luminance detection was finished before the letter was processed, which did not lead to any effects of the letters. In this experiment however, luminance detection and letter processing might have finished at a similar time, which then caused a delay if the global and local level were inconsistent. The fact that mismatching conditions only led to longer RTs for responses that seemed to be rather fast within this experiment suggests the occurrence of a bottleneck for fast but not for slow responses. More specifically, this means that for fast responses, there were no additional capacity-sharing resources, so any mismatch of the letters interfered with responses to the luminance. Lastly, it has to be mentioned that the findings of this experiments partly match with the findings of experiment 1, where the interference effect occurred consistently for the letter H but not for the letter I.

2.3.3 Experiment 4: Second-least luminance contrast

The previous experiment showed that interference effects occurred for conditions where responses that seemed to be rather fast, although this link was not statistically significant. Another experiment with less luminance contrast was conducted, predicting that longer responses for mismatching letters should still occur for conditions with rather fast responses within this experiment, according to the cognitive control theory. According to the bottleneck theory, interference effects would occur if the two processes of luminance detection and letter processing can be brought closer together in time. This was aimed to be done by slowing down responses overall.

2.3.3.1 Methods

Participants

25 students from the University of Birmingham took part in the experiment in exchange for course credits or monetary compensation. The inclusion criteria were normal or corrected-to-normal vision and normal colour vision. The mean age was 19.72 years (SD: 0.78), all participants were female, and 25 participants were right-handed.

Stimuli, Procedure, Design and Analysis

The experimental stimuli, procedure, design and analysis were the same as in experiments 2 and 3, apart from that this time, the luminance level between bright (RGB values: 165) and dark letters (RGB values: 134) was further reduced. The exclusion criterion was again accuracy lower than 90%. According to this criterion, one participant had to be excluded from the analysis. Outlier removal was based on the same criteria as before and according to this, all trials with RTs higher than 1.47 s were excluded from the analysis.

2.3.3.2 Results

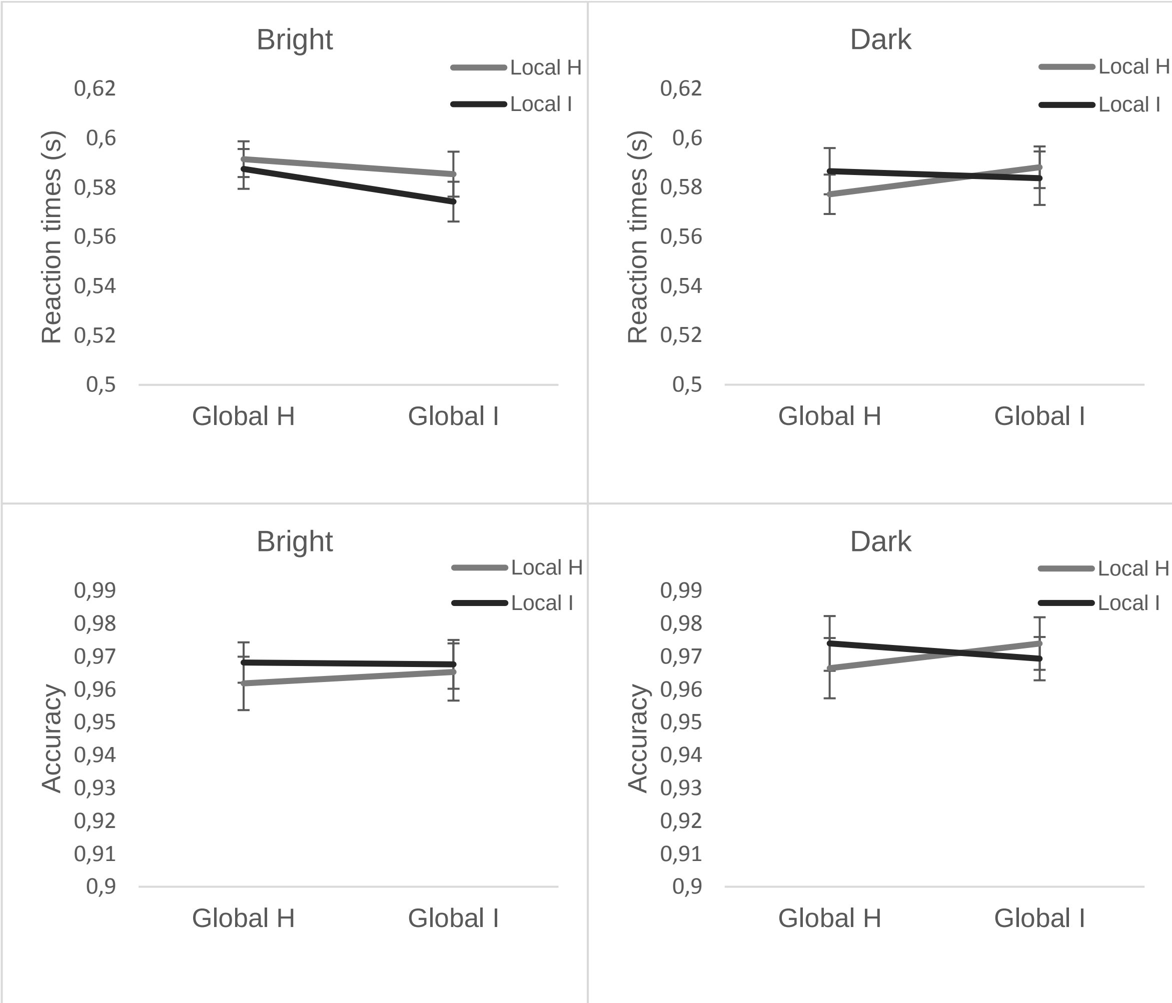


Figure 10: Results of the second-least luminance experiment (global level)
Experiment 4: For global H, there were no effects of local letter, whilst for global I, participants responded faster if the local letter was also an I. As there were no significant effects on accuracy, there was no speed-accuracy trade-off.

Reaction times

There was no significant main effect of luminance, $F(1,23)=.017$, $p=.896$, $\eta^2_p=.001$. The main effects of global letter, $F(1,23)=1.182$, $p=.288$, $\eta^2_p=.049$, and local letter, $F(1,23)=1.007$, $p=.326$, $\eta^2_p=.042$, were not significant either. The interactions luminance x global letter, $F(1,23)=5.085$, $p=.034$, $\eta^2_p=.181$, and global letter x local letter, $F(1,23)=5.145$, $p=.033$, $\eta^2_p=.183$, were significant. None of the other interactions were significant. To further examine the significant interactions, simple effect analyses were completed on both global H and I separately.

For global H, there were no significant main effects of luminance, $F(1,23)=1.694$, $p=.206$, $\eta^2_p=.069$, nor of local letter, $F(1,23)=.676$, $p=.419$, $\eta^2_p=.029$. The interaction was not significant either.

For global I, there was a significant main effect of local letter, $F(1,23)=4.775$, $p=.039$, $\eta^2_p=.172$. Participants responded faster to a local I (M:0.579, SD:0.069) than to a local H (M:0.587, SD:0.069). The main effect of luminance, $F(1,23)=.717$, $p=.406$, $\eta^2_p=.030$, and the interaction were not significant.

Accuracy

There were no significant effects.

2.3.3.3 Discussion

This time, an interference effect occurred for a global I but not for a global H. As predicted, for a global I responses were faster if the local letter was also an I. At the same time, responses trended to be faster for a global I than for a global H. Although this effect of global I vs. global H was not significant, it would support the assumptions made based on the discussion of the previous experiment, stating that mismatching conditions only lead to slower responses if responses are overall fast within an experiment. This would confirm the cognitive control theory. The bottleneck theory can also explain the results in this experiment. The competition between luminance detection and letter identification leads to interference (Appelbaum et al., 2012; Broadbent, 1958; Dyer, 1971; Glaser, & Glaser, 1982; Starrevald, & La Heij, 2017). However, the bottleneck theory does not explain why in this experiment, the interference effect occurred for an I but not for an H. To find further support for an exact time-frame in which interference effects might occur, a last experiment with even less luminance contrast between the letters was carried out, predicting generally slow responses for this experiment due to the low luminance contrast.

2.3.4 Experiment 5: Least luminance contrast

This experiment was conducted in order to test whether interference effects still occur for responses that are rather fast within this experiment, even if responses are predicted to be slower in this experiment than in the previous experiments, due to the low luminance contrast.

2.3.4.1 Methods

Participants

26 students from the University of Birmingham took part in the experiment in exchange for course credits or monetary compensation. The inclusion criteria were normal or corrected-to-normal vision and normal colour vision. The mean age was 19.11 years (SD: 1.31), 23 participants were female and 24 participants were right-handed.

Stimuli, Procedure, Design and Analysis

The experimental stimuli, procedure, design and analysis were the same as in experiments 2, 3 and 4, apart from that this time, the luminance level between bright (RGB values: 162) and dark letters (RGB values: 138) was further reduced. The exclusion criteria was again accuracy lower than 90%. According to this criterion, one participant had to be excluded from the analysis. Outlier removal was based on the same criterion as before and according to this, all trials with RTs higher than 1.43 s were excluded from the analysis.

2.3.4.2 Results

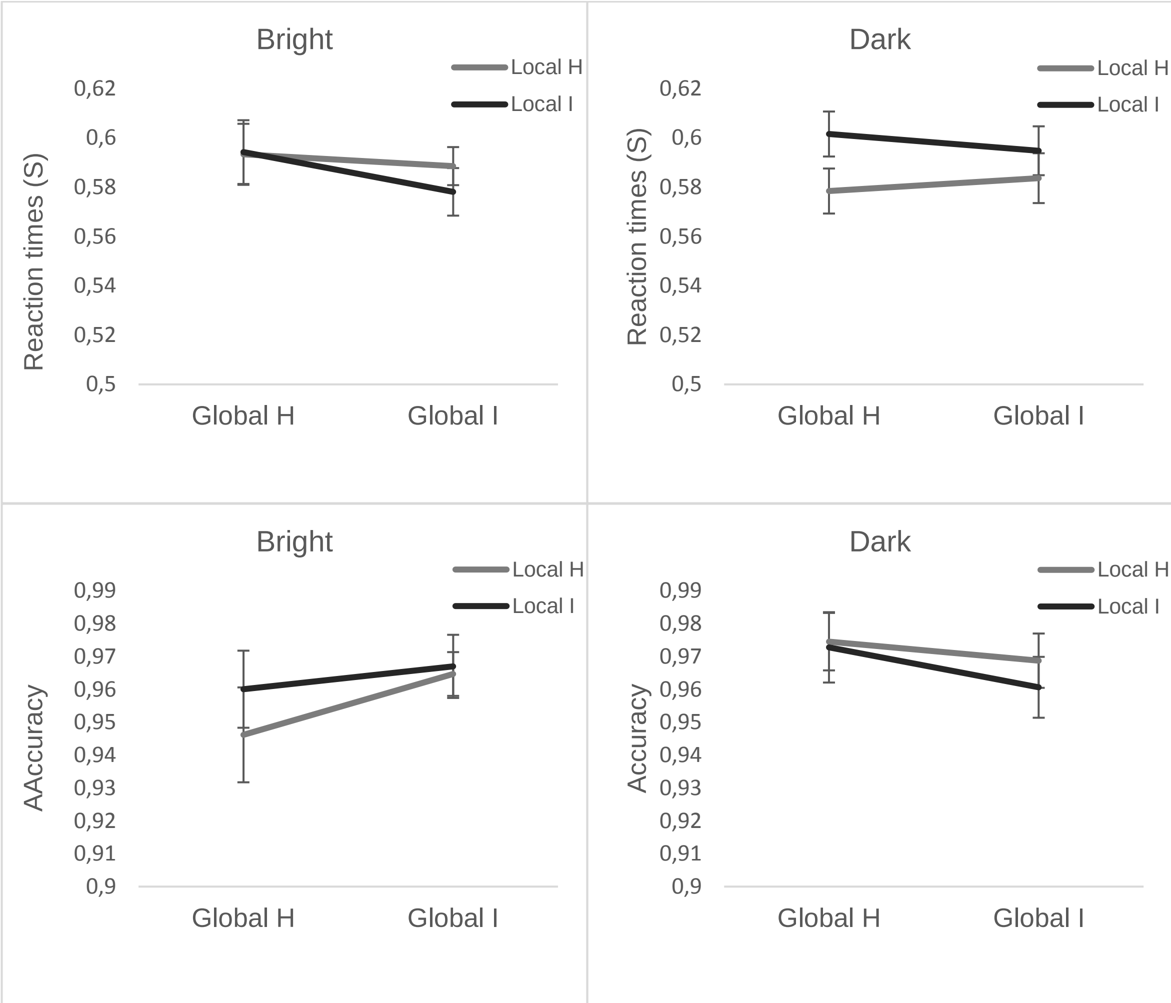


Figure 11: Results of the least-luminance contrast experiment (global level)
Experiment 5: For dark letters, participants responded faster if the local letter was an H There was no speed-accuracy trade-off.

Reaction times

There were no significant main effects of luminance, F(1,23)=.026, p=.873, η^2_p=.001, nor of global letter, F(1,23)=3.575, p=.071, η^2_p=.135, or of local letter, F(1,23)=4.189, p=.052, η^2_p=.154. The interaction luminance x local letter, F(1,23)=8.697, p=.007, η^2_p=.274, was significant. None of the other interactions were significant. To further examine the significant interaction, t-tests for dark vs. bright letters were completed for both local H and I separately. For both local letters, the effects of luminance were not significant. Therefore, t-tests for local H vs. local I were conducted for both luminance levels separately. There was a significant effect for dark letters, t(23)= -3.961, p=.001. Participants were faster for a local H (M:0.581, SD:0.101) than for a local I (M:0.598, SD:0.112).

Accuracy

There were no significant main effects of luminance, F(1,23)=3.127, p=.090, η^2_p=.120, nor of global letter, F(1,23)=.375, p=.546, η^2_p=.016, or of local letter, F(1,23)=.002, p=.964, η^2_p<.001. The interaction luminance x global letter, F(1,23)=6.985, p=.015, η^2_p=.233, was significant. None of the other interactions were significant. To further examine the significant interactions, t-tests were conducted for global H and global I separately. There was a significant effect for global H, t(23)= -2.372, p=.026. Participants were more accurate for dark (M:0.960, SD:0.678) than for bright letters (M:0.936, SD:0.087). As there were no interactions of global letter and luminance for RTs, there was no speed-accuracy trade-off.

2.3.4.3 Discussion

This time, there was no interaction between the global level and the local level at all. It is possible that a mismatch between the global and the local level does not lead to slower responses for a very high (experiment 2) or a very low (this experiment) luminance contrast, but only for an "ideal" luminance contrast in-between. However, even for the experiments with the "ideal" luminance contrast where interference effects occurred, faster responses to matching conditions seemed to be linked to responses that trended to be fast within those experiments. To get more insight into the results and to compare them across all experiments together, a between-experiments analysis was conducted. A further aim of the between-experiments analysis was to increase power.

2.4 Between-experiments analysis

To compare the different conditions (luminance, global letter and local letter) across all four experiments together and to increase power, a between-experiments analysis was conducted with the aim to establish if faster responses to matching conditions are linked to rather fast responses, as it could be concluded from the results of experiments 2 and 3.

2.4.1 Methods

A mixed ANOVA with the within-subjects factors luminance (bright or dark), global letter (H or I) and local letter (H or I) and the between-subject factor experiment (2-5) was conducted on RTs (in s) and accuracy.

2.4.2 Results

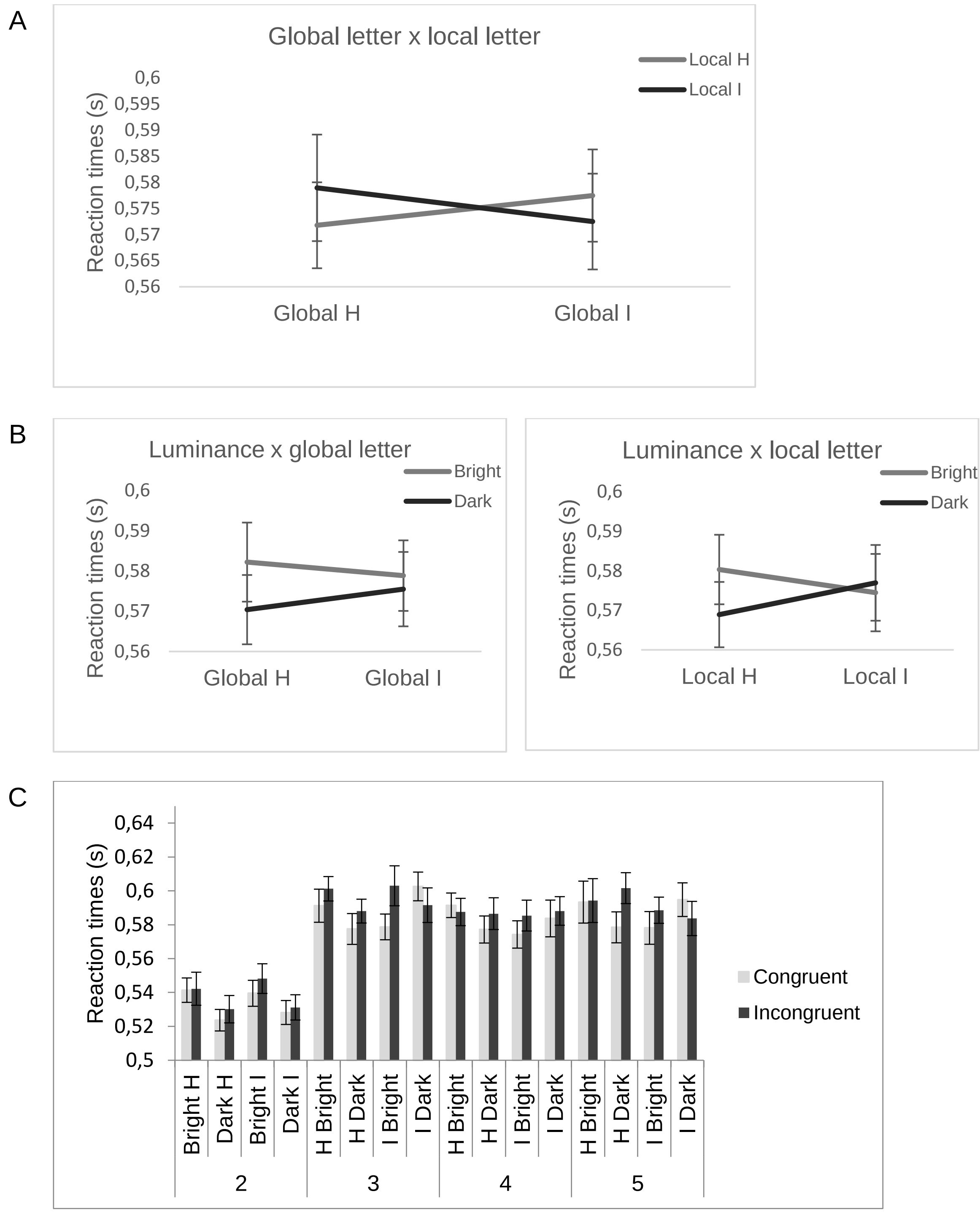


Figure 12: Between-experiments analysis (global level)
A: Illustration of the interaction global letter x local letter in the between-experiments analyses. Participants responded generally faster if the global letter and the local letter were the same, which matches the prediction. B: Left graph: Illustration of the interaction luminance x global letter. Participants responded slower to bright letters, but only if the global letter was an H. Right graph: Illustration of the interaction luminance x local letter. Again, participants responded slower to bright letters, but only if the local letter was an H. C: Illustration of RTs for all four experiments and the different conditions (bright and dark letters, congruent and incongruent global H and I).

Reaction times

There were no significant main effects of luminance, $F(1,94)=2.111$, $p=.150$, $\eta^2_p=.022$, of global letter, $F(1,94)=.069$, $p=.793$, $\eta^2_p=.001$, nor of local letter, $F(1,94)=.666$, $p=.416$, $\eta^2_p=.007$. There was also no main effect of experiment, $F(3,94)=2.296$, $p=.083$, $\eta^2_p=.068$. The interactions luminance x global letter, $F(1,94)=13.461$, $p<.001$, $\eta^2_p=.125$, luminance x local letter, $F(1,94)=21.052$ $p<.001$, $\eta^2_p=.183$, global letter x local letter, $F(1,94)=14.840$, $p<.001$, $\eta^2_p=.136$ and luminance x global letter x local letter x experiment, $F(3,94)=3.116$, $p=.030$, $\eta^2_p=.090$ were significant. None of the other interactions were significant. To further examine the significant interactions, simple effect analyses were conducted for both global H and I separately.

For global H, the main effect of luminance was significant, $F(1,94)=8.283$, $p=.005$, $\eta^2_p=.081$. Participants responded faster when the letters were dark (M:0.570, SD:0.089) than when they were bright (M:0.580, SD:0.089). The main effect of local letter was also significant, $F(1,94)=11.995$, $p=.001$, $\eta^2_p=.113$. Participants responded faster when the local letter was an H (M:0.572, SD:0.089) than when it was an I (M:0.579, SD:0.089). The main effect of experiment was not significant, $F(3,94)=2.378$, $p=.075$, $\eta^2_p=.071$. Finally, the interaction luminance x local letter was significant, $F(1,94)=5.841$, $p=.018$, $\eta^2_p=.059$. None of the other interactions were significant. To further examine the significant interaction, simple effect analyses were conducted on both bright and dark global H separately.

For bright global H, there were no significant effects.

For dark global H, there was a significant main effect of local letter, $F(1,94)=21.766$, $p<.001$, $\eta^2_p=.188$. Participants responded faster when the local letter was an H (M:0.564, SD:0.088) than when it was an I (M:0.577, SD:0.097). The main effect of experiment, $F(3,94)=2.568$, $p=.059$, $\eta^2_p=.076$, and the interaction local letter x experiment were not significant.

For global I, there was also a significant main effect of local letter, $F(1,94)=5.748$, $p=.018$, $\eta^2_p=.058$. Participants responded faster when the local letter was an I (M:0.572, SD:0.089) than when it was an H (M:0.579, SD:0.089). The interactions local letter x luminance, $F(1,94)=21.945$, $p<.001$, $\eta^2_p=.189$, and local letter x luminance x experiment, $F(1,94)=3.597$, $p=.016$, $\eta^2_p=.103$, were significant as well. None of the other interactions were significant. The main effects of luminance, $F(1,94)=.090$, $p=.765$, $\eta^2_p=.001$, and of experiment, $F(3,94)=2.212$, $p=.092$, $\eta^2_p=.066$, were not significant either. To further examine the significant interactions, simple effect analyses were conducted on both bright and dark global I separately.

For bright global I, there was a significant main effect of local letter, $F(1,94)=25.478$, $p<.001$, $\eta^2_p=.213$. Participants responded faster when the local letter was an I (M:0.568, SD:0.088) than when it was an H (M:0.581, SD:0.088). The main effect of experiment was not significant, $F(3,94)=1.400$, $p=.248$, $\eta^2_p=.043$. The interaction local letter x experiment was not significant either.

For dark global I, the main effect of experiment was significant, $F(3,94)=3.027$, $p=.033$, $\eta^2_p=.088$. Participants responded fastest for experiment 2 (M: 0.530, SD:0.175), second-fastest for experiment 4 (M:0.586, SD:0.175), second-slowest for experiment 5 (M: 0.589, SD:0.175) and slowest for experiment 3 (M:0.597, SD:0.175). The main effect of local letter, $F(1,94)=1.669$, $p=.200$, $\eta^2_p=.017$, and the interaction local letter x experiment were not significant.

Accuracy

The main effect of luminance was significant, $F(1,94)=9.114$, $p=.003$, $\eta^2_p=.088$. Participants were more accurate for dark (M:0.964, SD:0.039) than for bright (M:0.957, SD:0.048) letters. As there was no significant main effect of luminance on RTs, there was no speed-accuracy trade-off. The main effects of global letter, $F(1,94)=.373$, $p=.543$, $\eta^2_p=.004$, local letter, $F(1,94)=.314$, $p=.577$, $\eta^2_p=.003$, and experiment, $F(3,94)=.879$, $p=.455$, $\eta^2_p=.027$, were not significant. The interaction luminance x global letter, $F(1,94)=8.856$, $p=.004$, $\eta^2_p=.086$, was significant. None of the other interactions were significant. To further examine the significant interaction, simple effect analyses were conducted on both global H and global I separately.

For global H, the main effect of luminance was significant, $F(1,94)=12.683$, $p=.001$, $\eta^2_p=.119$. Participants were more accurate for dark (M:0.966, SD:0.039) than for bright letters (M:0.954, SD:0.048). As participants also responded faster for dark letters, there was no speed-accuracy trade-off. The main effect of local letter,

$F(1,94)=2.389$, $p=.126$, $\eta^2_p=.025$, and of experiment, $F(3,94)=.888$, $p=.450$, $\eta^2_p=.028$, were not significant. None of the interactions were significant. For global I, there were no significant effects.

2.4.3 Discussion

The between-experiments analysis provided further evidence for the influence of speed on the occurrence of interference effects. An interference effect only occurred for a dark but not for a bright H. At the same time, participants responded significantly faster to a dark than to a bright H. The same pattern could be shown for I. Interference effects occurred for a bright I but not for a dark I. At the same time, participants responded relatively faster to a bright I than to a dark I, although this effect of speed of responses was not significant. The results indicate that the occurrence of interference effects seems to be linked to the speed of responses. The results also show that interference effects occur for both letters, H and I, and for both luminance levels, bright and dark.

2.5 General Discussion

This series of experiments aimed to find out whether Navon stimuli are still processed, even if participants do another task, which is completely independent. More specifically, we predicted that matching conditions in Navon stimuli still lead to faster responses and mismatching conditions evoke slower responses, even when the stimuli are not task-relevant. On the other hand, it could be equally possible that task-irrelevance would not lead to any interference effects at all. Rendering the Navon stimuli task-irrelevant was operationalised by asking the participants to respond to the luminance (bright or dark) of the global letter (H or I, matching or mismatching conditions) instead of responding to the letter itself. First of all, we conducted the classic Navon experiment to see whether interference effects can be obtained with our stimuli (H and I). Two standard findings could be confirmed: participants responded faster to congruent stimuli and they responded faster on the global level. However, the occurrence of interference effects was not independent of letter identity. For H, interference effects occurred on both the global and the local level, whilst for I, they only occurred on the global level. When rendering the Navon stimuli task-irrelevant, we used four different luminance contrast conditions (experiments 2-5, figure 7), as it has been shown that interference effects are dependent on the speed of responses. It has been shown that decreasing the luminance contrast increases RTs (Plainis, & Murray, 2000; Walkey et al., 2006), therefore the aim of manipulating luminance contrast was to influence speed of responses, which in turn should influence the time-course of interference effects. Specific predictions were made about this time-course of interference effects, based on different theories.

According to the cognitive control theory, interference effects should only occur for generally fast responses, when cognitive control is not yet available to squash the processing of the irrelevant dimension (Bialystok et al., 2004; Coderre, & van Heuven, 2014; Jansma et al., 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984; Shiffrin, & Schneider, 1977; Stuss et al., 2001; White et al., 2018).

In line with the bottleneck theory interference effects occur if two processes are happening simultaneously (Appelbaum et al., 2012; Broadbent, 1958; Dyer, 1971; Glaser, & Glaser, 1982; Lu, & Proctor, 2001; Roelofs, 2010; Starrevald, & La Heij, 2017). In our series of experiments, these two processes are letter identification and luminance detection. While it is difficult to make specific predictions regarding the timing of the two tasks involved a-priori, the idea is that it is possible to bring the two tasks closer together in time, subsequently increasing the likelihood of interference. This yields into the prediction of a reverse U-shaped function (Pashler, & Johnston, 1988), suggesting that interference effects should not occur for fast or slow responses, therefore they should not occur for a high or low luminance contrast.

The results of our series of experiments showed that matching conditions generally led to faster responses (figure 12), but this seemed to be only the case for responses that were numerically responded to relatively fast (dark H and bright I) but not for conditions that were responded to more slowly (bright H and dark I), as shown in the between-experiments analysis. It has to be mentioned that the effect of speed was only significant for H but not for I. The analyses of all four experiments separately showed that no interference effects could be obtained for the highest and the lowest luminance contrast (experiments 2 and 5). As interference effects seemed to occur for conditions were responses were rather fast (i.e. dark H and bright I), it can be said that the time-course seemed to matter. It is important to note that interference effects occurred for both letters H and I and for both luminance responses, bright and dark.

Effects of luminance contrast manipulation

There was no main effect of experiment, therefore we did not succeed in manipulating the speed of responses by manipulating the different luminance contrasts. Another prediction that we made about luminance was that dark letters would be processed faster and more accurately (Buchner, and Baumgartner, 2007; Komban et al., 2001). However, dark letters were only processed faster in the condition with the highest luminance contrast (experiment 2) and more accurately in experiment 3 (second-highest luminance contrast). Nevertheless, the between-experiments analysis showed that participants were faster and more accurate for a dark H than for a bright H. Therefore, it can be concluded that predictions for dark vs. bright letters could be partly supported.

Evidence for cognitive control

One explanation why interference effects only seemed to occur for fast responses could be the cognitive control theory. It is likely that for conditions with rather slow responses within experiments, efficient cognitive control abolished the occurrence of interference effects, whilst this process did not take place for rather fast responses within experiments. However, one weakness of this explanation is that the difference in fast vs. slow responses was only significant in certain conditions. For example. an interference effect occurred for a dark H but not for a bright H and at the same time, participants responded significantly faster to a dark H than to a bright H, providing evidence for the cognitive control theory. An interference effect also occurred for a bright I but not for a dark I. Although participants seemed to respond at the same time faster to a bright I than to a dark I, which would again support the cognitive control theory, this difference in speed was not statistically significant in those conditions. The time-course predictions of interference effects between experiments can only be partially explained with the cognitive control theory. For example, no interference effects occurred for the condition with the highest luminance contrast (experiment 2). However, according to the cognitive control theory, this experiment should have led to interference effects, because responses were rather fast in this experiment. The lack of interference effects in this experiment could be explained by attentional capture (e.g. Theeuwes, 2004; Yantis, 1993, Yantis, & Jonides, 1984). Attentional capture means that attention is involuntarily directed towards a stimulus based on the characteristics of that stimulus (Yantis, & Jonides, 1984), for example based on its saliency. Research has shown that a salient target consequently leads to quick response times (see also van Zoest et al., 2012). This would prevent high-level identity information from interfering with lower-level identity information (e.g. Moher et al., 2019; van Zoest et al., 2012, Zehetleitner et al., 2012). The lowest luminance contrast condition did not cause any interference effects either (experiment 5), which would be in line with the time-course prediction of the cognitive control theory. The lack of interference effects could be explained by the additional attentional resources that were needed in this condition. This can be combined with the perceptual load theory proposed by Lavie in 1995, which states that in a condition with high perceptual load (e.g. a target surrounded by many distractors that are hard to distinguish from the target), the target will be selected quickly and the distractors will be filtered out, due to the attentional resources that are needed. In contrast, in a condition with low perceptual load (e.g. a target surrounded by just a few distractors that can be easily distinguished from the target), fewer attentional resources are needed, leading to the processing of distractors and potentially causing interference. When looking at the time-course of interference effects between experiments, it also has to be mentioned that the luminance contrast manipulation of experiments was not successful, as there was no main effect of experiment.

Evidence for the bottleneck theory

It could be assumed that in our series of experiments participants responded to the luminance whilst they were still processing the letter, which led to interference because a bottleneck occurred. Within experiments, this interference effect occurred for conditions with rather fast responses (i.e. dark H and bright I). In contrast, in the conditions with the slower responses (i.e. bright H and dark I), participants had already fully processed the letter at the time they responded to the luminance. This means that the two processes happened in serial and therefore, no interference effects occurred. Therefore, a bottleneck occurring for rather fast responses can be assumed. When looking at the time-course between experiments, it has to be noted that no interference effects occurred neither for the experiment with the highest luminance contrast (experiment 2) nor for the condition with the lowest luminance contrast (experiment 5). This means that the predicted reverse U-shape function was confirmed (Pashler, & Johnston, 1988). However, it has to be highlighted again that the luminance manipulation of the different experiments was not successful, as there was no main effect of experiment. In general, the explanation of the results by using the bottleneck theory has some important weaknesses. Typical experiments that investigate the bottleneck-theory in a dual task paradigm use two separate tasks that also require separate responses (e.g. Kunar et al., 2008; Pashler, 1994; Pashler, & Johnston, 1989). Instead, in our experiment, participants were only asked to respond to the luminance but not to letter identity. In addition, the researchers that looked in the SOA interval in the Stroop task (Appelbaum et al., 2012; Dyer, 1971; Glaser, & Glaser, 1982; Lu, & Proctor, 2001; Roelofs, 2010; Starrevald, & La Heij, 2017) actively manipulated that SOA interval between word and colour, whilst we did not manipulate the SOA interval between letter and luminance.

Unexplained other effects

There are two final important points to make. First, the results of our series of experiments partly contradict the results of the standard Navon task (experiment 1), as in the standard Navon task, interference effects did not occur on the global level for the letter I. This could be explained by Gestalt grouping principles. Participants might have been more likely to group local Hs than local Is (Han et al., 1999, Rock, & Palmer, 1990). This difference between the two letters might have occurred because the letter H that was used in this series of experiments could be seen as a more typical representative of a letter than I (e.g. Maxfield et al., 2014; Rosch et al., 1976). However, in our series of experiments interference effects occurred for both letters. Second, this series of experiments experiment was set up as a global level task, considering that participants were asked to respond to the luminance of the whole letter. In accordance with global precedence, incongruence would not produce interference effects when participants attend to the stimuli on the global level (Lamb, 1996; Navon, 1977; 1981). However, in this series of experiments, an interference effect occurred, which challenges the theory of global precedence. There are several studies supporting the fact that interference can occur on both the global and the local level (e.g. Martin, 1979, Grice et al., 1983; Heinze, & Münte, 1993; see Kimchi, 1992, for a critical review). To find out whether the same effects occur if participants are instructed to attend to the local level, another series of experiments was conducted.

Chapter Three: LOCAL LETTER LUMINANCE EXPERIMENTS

3.1 Introduction

In the previous chapter, task-irrelevant interference effects were investigated when attention was directed to the global level. The Navon letters were rendered task-irrelevant by asking participants to respond to the luminance of a whole global letter, which was embedded in a square. The global and local level either matched, meaning that the letters were congruent (a global H that consisted of local Hs or a global I that consisted of local Is) or the global and local level did not match, meaning that the letters were incongruent (a global H made out of local Is or a global I made out of local Hs). In this chapter, the same letters were used as in the previous chapter (matching or mismatching H and I) but this time a dot was embedded in one of the local letters in order to create a local-level focus. The dot was implemented either in the middle right or middle left local letter of the global H, or in the middle top or middle bottom local letter of the global I (see figure 14, for an illustration). In the present chapter, task-irrelevance was manipulated by asking participants to indicate whether the dot embedded in one of the local letters was brighter or darker than its surrounding letter.

The luminance contrasts between bright and dark stimuli were higher than in the previous experiment, because this task was predicted to be overall more difficult than the task in the previous chapter. We predicted that task-irrelevant interference effects would occur: participants were expected to respond faster if the global and local identity of the letters matched than when they did not match (figure 13). The predictions for the time-course of interference effects based on the cognitive control theory (Bialystok et al., 2004; Coderre, & van Heuven, 2014; Jansma et al., 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984; Shiffrin, & Schneider, 1977; Stuss et al., 2001; White et al., 2018) and the bottleneck theory (Appelbaum et al., 2012; Broadbent, 1958; Dyer, 1971; Glaser, & Glaser, 1982; Lu, & Proctor, 2001; Roelofs, 2010; Starrevald, & La Heij, 2017) remained the same as for the previous chapter. This means that for the cognitive control theory, it was predicted that within each experiment, interference effects were predicted to occur for responses that should be rather fast, i.e. for dark dots (e.g. Buchner, & Baumgartner, 2007; Komban et al., 2001). Between experiments, interference effects were predicted to also occur for conditions that should elicit fast responses, i.e. for conditions with a high luminance contrast (Plainis, & Murray, 2000; Walkey et al., 2006). In contrast, for a low luminance contrast and for bright dots, responses were predicted to be slower and therefore no interference effects should occur. According to the reversed U-shape prediction of the bottleneck theory (Pashler, & Johnston, 1988), no interference effects should occur neither for the highest nor for the lowest luminance contrast conditions, where responses were predicted to be particularly fast and particularly slow.

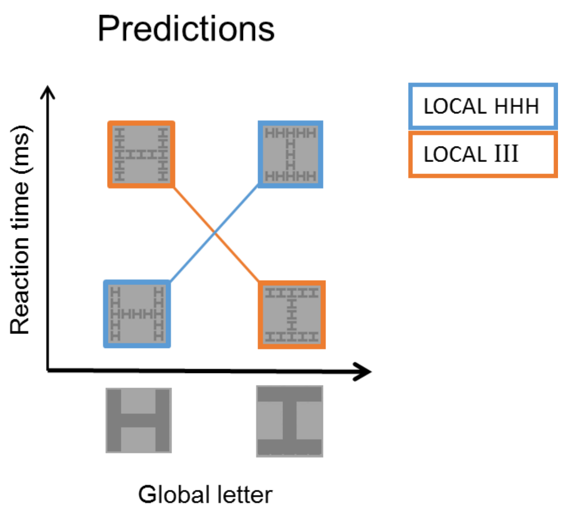


Figure 13: Predictions of interference effects
Predictions about the occurrence of interference effects with our stimuli.

It is important to be clear about the terminology again. As both the global and the local level of the Navon stimuli were task-irrelevant, the words matching vs. mismatching were used rather than congruent vs. incongruent. However, when referring to the literature in the discussion, it is not always possible to make a clear distinction between matching vs. mismatching and congruent vs. incongruent, therefore these terms may be used interchangeably. Because the relevant task (luminance decision) is irrelevant of the letter identity, the analysis was done based on the different letters in order to find out whether different letter identity would drive the effects. Another rationale for separating the analysis into different letter identities was that already the classic Navon task showed differences between the different letters H and I (chapter 2, experiment 1). For H, interference effects occurred on both the global and the local level, whilst for I, they only occurred on the global level. The analysis was also split in bright vs. dark dots.

Two different predictions can be made about the occurrence of the task-irrelevant interference effects with taking this specific local-level focus into account. On the one hand, it could be assumed that despite doing a task on the local level, participants still take the whole global letter into account, which can be supported by studies using Navon letters or similar stimuli. Independent of local or global precedence, there is generally an interference effect, especially on the local level. This suggests that especially if there is a local level focus, participants still take the whole global letter into account and interference effects are usually less strong if there is a global-level focus (e.g. Hoffmann, 1980; Martin, 1979; Navon, 1977; 1981). This might explain the lack of consistent interference effects in the previous chapter. It was predicted that in contrast to the previous series of experiments responses should be slower in this new series of experiments. This prediction was made based on the global precedence theory, which states that responses are faster when participants respond on the global level (e.g. Navon, 1977; 1981). An additional rationale for the assumption of slower responses in this task would be that in this new series of experiments, participants respond to a small dot, rendering the luminance response overall more difficult compared to the luminance response of the whole global letter in chapter 2.

On the other hand, it could be assumed that no interference effects would occur at all for this series of experiments, as previous research has shown that a local level focus of a global-local task can narrow down the attentional window and make global information inaccessible (Gasper, & Clore, 2002; Huntsinger et al., 2010). Another assumption for the lack of occurrence of interference effects in a local level focus task could be derived from looking into the study conducted by Besner et al. (1997). They found that the Stroop effect could be eliminated when just one single colour instead of the whole word was coloured. Although there are clear differences between the Stroop task and the set-up of our experiment, the finding of this experiment could serve as an additional rationale taking the specifics of this series of experiments into account.

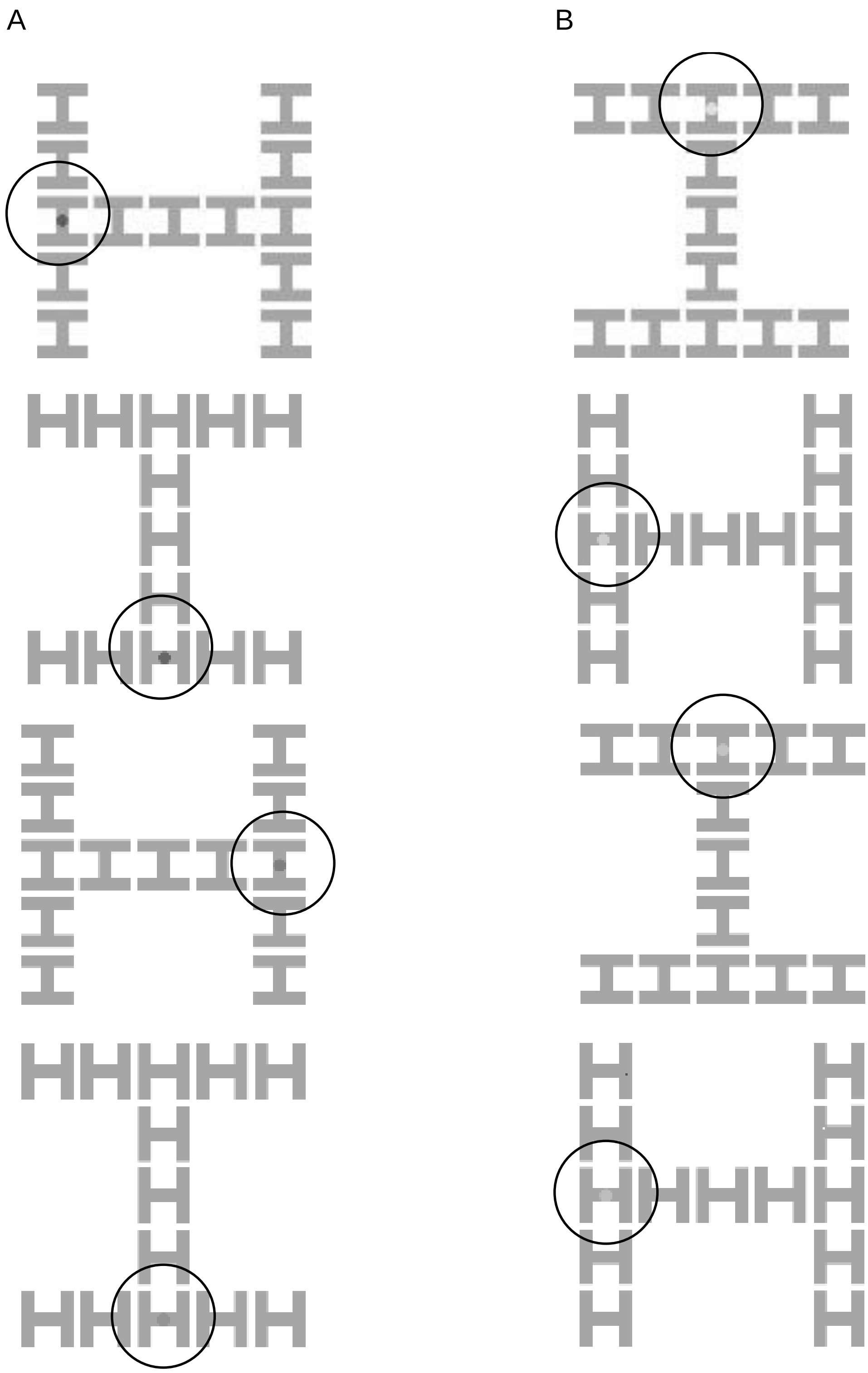


Figure 14: Stimuli of the local level condition
From top to bottom: Experiments 1-4 (highest to lowest luminance contrast). Panel A: The first image contains a dark dot embedded in a global H made up of local Is, which means that the global and local level of the letters is different (mismatching condition). The second image contains a dark dot embedded in a global I made up of local Hs (mismatching condition). Panel B: The first image is a bright dot embedded in a global I made up of local Is, which means that the global and local level of the letters is the same (matching condition). The second image is a bright dot embedded in a global H made up of local Hs (matching condition).

3.2 Experiment 1: Highest luminance contrast

3.2.1 Methods

Participants

22 students from the University of Birmingham took part in the experiment in exchange for course credits or monetary compensation. The inclusion criteria were normal or corrected-to-normal vision and normal colour vision. The mean age was 19.14 years (SD:0.77), 18 participants were female and 21 participants were right-handed.

Stimuli

A big global letter that was an H or an I (7.6°) and that was made out of smaller local letters, again H or I (1.5°), was presented in the centre of the computer screen. The letters were grey and they were presented against a white background. If the big letter was made out of the same smaller letters (e.g. an H made out of Hs), the global and local level matched (congruent conditions) and if the big letter was made out of different small letters (e.g. an H made out of Is), the global and local level did not match (incongruent conditions). One of the smaller letters contained a small dot (0.3°). If the big letter was an I, the dot was in the middle top or middle bottom local letter, and if the big letter was an H, the dot was in the middle left or middle right local letter. The dot was either brighter (RGB values: 217) or darker (RGB values: 77) than its surrounding letter (RGB values: 149).

Procedure

Participants were seated 45 cm in front of a computer screen in a darkened room. Before every trial, a black fixation cross (0.9°) appeared in the centre of a black screen. After 2000 ms, the global letter made out of smaller letters was presented. Participants were asked to press the corresponding keys according to the dot brightness (k for brighter and m for darker) on a computer keyboard. The letter remained on the computer screen until participants made a response.

Design

The experiment consisted of 6 blocks with 96 trials each. Before the start of the experiment, participants had to complete 12 practice trials. In each block, the number of the two different global letters and of matching and mismatching conditions was balanced. The quantity of trials that contained a bright and a dark dot was equalised as well.

Analysis

A repeated measures ANOVA with the factors luminance (bright or dark), global letter (H or I) and local letter (H or I) was conducted on RTs (in s), accuracy and the inverse efficiency score in s (IES, Townsend, & Ashby, 1978, 1983). The IES was calculated by dividing RTs (in s) through correct responses (in percentages) in order to account for any possible speed-accuracy trade-offs. The exclusion criterion was accuracy lower than 95%. 5 participants had to be excluded from the analysis according to this criterion. Outlier removal was done based on RTs higher or lower than 2 SDs from the mean, meaning that all trials with RTs higher than 1.36 s were excluded.

3.2.2 Results

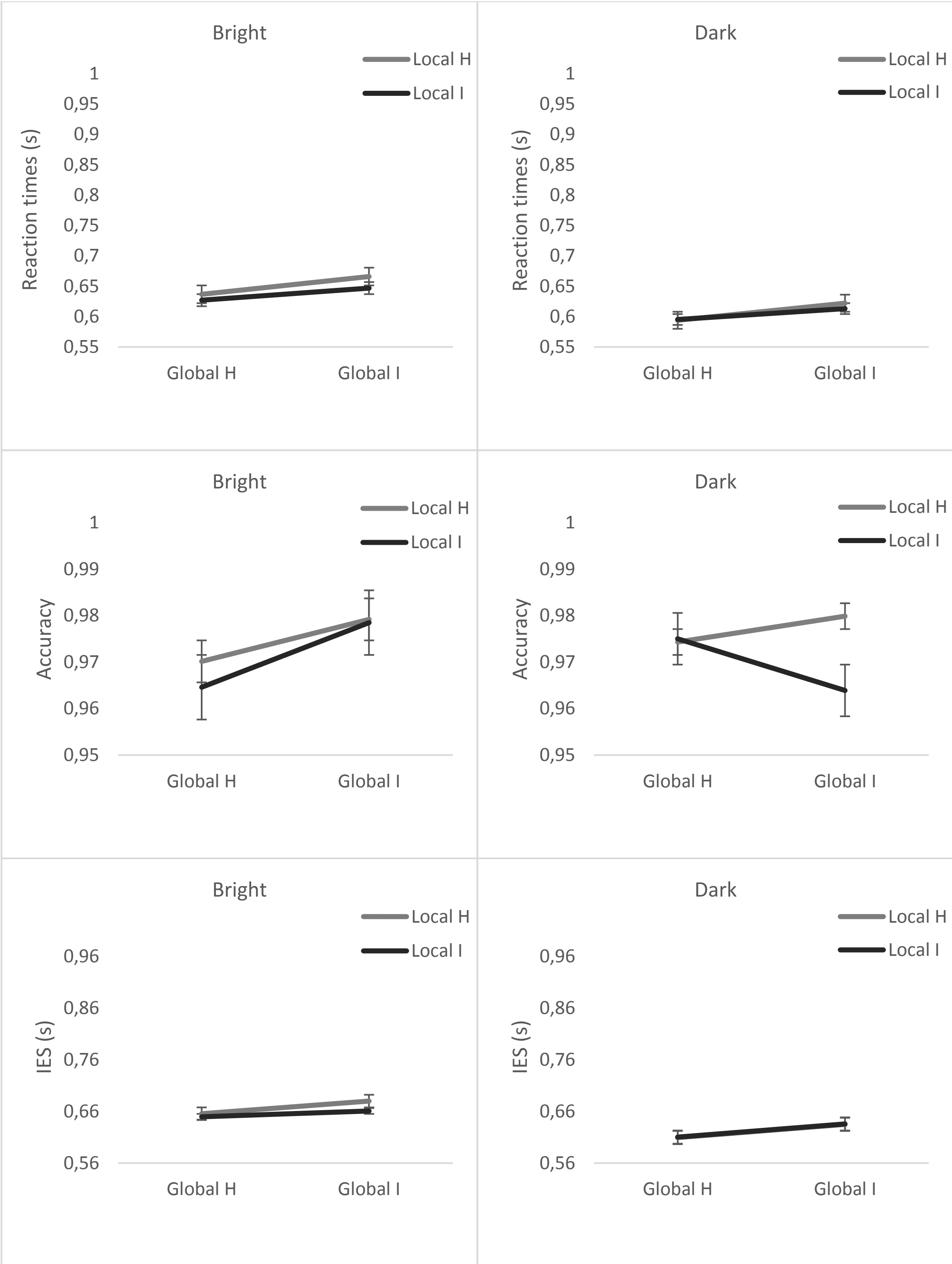


Figure 15: Results of the highest luminance contrast experiment (local level)
Experiment 1: Participants responded faster to dark dots and to a global H. For global H, participants responded faster to dark dots. For global I, participants also responded faster to dark dots and to a local I. There was no speed-accuracy trade-off.

Reaction times

There was a significant main effect of luminance, $F(1,19)=41.762$, $p<.001$, $\eta^2_p=.687$. Participants responded faster when the dots were dark (M:0.606, SD:0.089) than when they were bright (M:0.644, SD:0.094). The main effect of global letter was also significant, $F(1,19)=51.628$, $p<.001$, $\eta^2_p=.731$. Participants responded faster when the global letter was an H (M:0.613, SD:0.089) than when it was an I (M:0.637, SD:0.089). The main effect of local letter was significant as well, $F(1,19)=6.904$, $p<.001$, $\eta^2_p=.267$. Participants responded faster when the local letter was an I (M:0.621, SD:0.094) than when it was an H (M:0.630, SD:0.089). Finally, the interaction global letter x local letter was significant, $F(1,19)=4.747$, $p-.042$, $\eta^2_p=.200$, showing that only for the letter I, participants responded faster when the global and local letter matched. This was not the case for the letter H. None of the other interactions were significant. To further examine the significant interaction, simple effect analyses were completed for both global H and I separately.

For global H, the main effect of luminance was significant, $F(1,19)=41.527$, $p<.001$, $\eta^2_p=.686$. Participants responded faster to dark (M:0.595, SD:0.089) than to bright dots (M:: 0.632, SD:0.094).

For global I, the main effect of luminance was significant, $F(1,19)=34.144$, $p<.001$, $\eta^2_p=.642$. Participants responded faster to dark (M:0.618, SD:0.089) than to bright dots (M:0.656, SD:0.094). The main effect of local letter was also significant, $F(1,19)=8.295$, $p=.010$, $\eta^2_p=.304$, with participants responding faster when the local letter was an I (M:0.630, SD:0.094) than when it was an H (M:0.644, SD:0.089).

Accuracy

The main effects of global letter, $F(1,19)=1.338$, $p=.262$, $\eta^2_p=.066$, local letter, $F(1,19)=1.662$, $p=.218$, $\eta^2_p=.079$, and luminance, $F(1,19)=.003$, $p=.956$, $\eta^2_p<.001$, were not significant. The only significant interaction was global letter x luminance, $F(1,19)=5.007$, $p=.037$, $\eta^2_p=.209$. To further examine the significant interaction, simple effect analyses were conducted for both global H and I separately. For both letters, there were no significant effects.

IES

There was a significant main effect of luminance, $F(1,19)=38.342$, $p<.001$, $\eta^2_p=.669$. Participants performed better when the dots were dark (M: 0.622, SD:0.089) than when they were bright (M:0.663, SD:0.089). The main effect of global letter was also significant, $F(1,19)=29.248$, $p<.001$, $\eta^2_p=.606$. Participants showed better performance when the global letter was an H (M:0.631, SD:0.089) than when it was an I (M:0.653, SD:0.089). The main effect of local letter was not significant, $F(1,19)=1.382$, $p=.254$, $\eta^2_p=.068$. None of the interactions were significant.

3.2.3 Discussion

Participants' faster responses to dark dots can be best explained by the fact that the whole letter was presented against a white background, which made the luminance contrast between the white background and the dot larger and therefore made the dark dots more outstanding. Previous research has shown that RTs are shorter and performance is better for dark targets and for a high luminance contrast (Buchner, & Baumgartner, 2007; Komban et al., 2011; Plainis, & Murray, 2000; Walkey et al., 2006). Another important finding is that participants generally responded faster to a global H than to a global I. This can be explained by the embedment of the dots: for a global H, they were embedded horizontally, whilst for a global I, they were inserted vertically. It is a well-established finding that performance is better on the horizontal than on the vertical (e.g. Collewijn, & Taminga, 1984; Ingster-Moati et al., 2009; Schmidt et al., 1993; Yu et al., 2010).

Importantly, participants responded faster when the global and local letter matched, but this was only the case for the global letter I and not for H. It is unclear why this effect only occurred for one letter. The bottleneck theory (Broadbent, 1958) might serve as one explanation, as letter processing and luminance response might only have interfered for a global I but not for a global H. Another explanation for the occurrence of interference effects can be given when looking into experiments that investigated the time-course of the Stroop effect and found that the Stroop effect increases as response times increase (Bub et al., 2006; Cohen et al., 1990; Glaser, & Glaser, 1982). The Stroop effect, similar to our series of experiments, reflects stimulus-

stimulus compatibility (SSC; Kornblum, 1992), which means that responses are faster if two stimulus dimensions match than when they do not match. According to the findings about the time-course of the Stroop effect, interference effects occur for conditions where responses are slow, which was also found in this experiment. Our finding is also in line with the study of van Zoest et al. (2012), who found that interference effects in a stimulus-response compatibility (SRC) task increased as response times increased.

The cognitive control theory cannot explain the results in this experiment, as according to the time-course prediction of the cognitive control theory within experiments, interference effects should have occurred for conditions with rather fast responses within this experiment (Bialystok et al., 2004; Coderre, & van Heuven, 2014; Jansma et al., 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984; Shiffrin, & Schneider, 1977; Stuss et al., 2001; White et al., 2018). However, this was not the case. It was concluded that for less luminance contrast, the differences in response times for bright and dark dots would be less strong and that this might in turn lead to an occurrence of interference effects for both letters. Therefore, another experiment with less luminance contrast between the two dots was conducted.

3.3 Experiment 2: Second-highest luminance contrast

The results of the previous experiment revealed that interference effects occurred, but it was only the case for a global H and not for a global I. It was concluded that this difference in the interference effect for both letters might have been due to the relatively large luminance contrast between the dots, therefore the luminance contrast between bright and dark dots was reduced in this experiment.

3.3.1 Methods

Participants

24 students from the University of Birmingham took part in the experiment in exchange for course credits or monetary compensation. The inclusion criteria were normal or corrected-to-normal vision and normal colour vision. The mean age was

19.71 years (SD:1.16), 22 participants were female and 17 participants were right-handed.

Stimuli, Procedure, Design and Analysis

The experimental stimuli, procedure, design and analysis were the same as in experiment 1, apart from that this time the luminance difference between bright (RGB values: 196) and dark dots (RGB values: 83) was reduced. The exclusion criterion was again accuracy lower than 95% and according to this criterion, 4 participants had to be excluded from the analysis. Outlier removal was based on the same criterion as before and according to that, all trials with RTs higher than 1.13 s or lower than 0.25 s were excluded.

3.3.2 Results

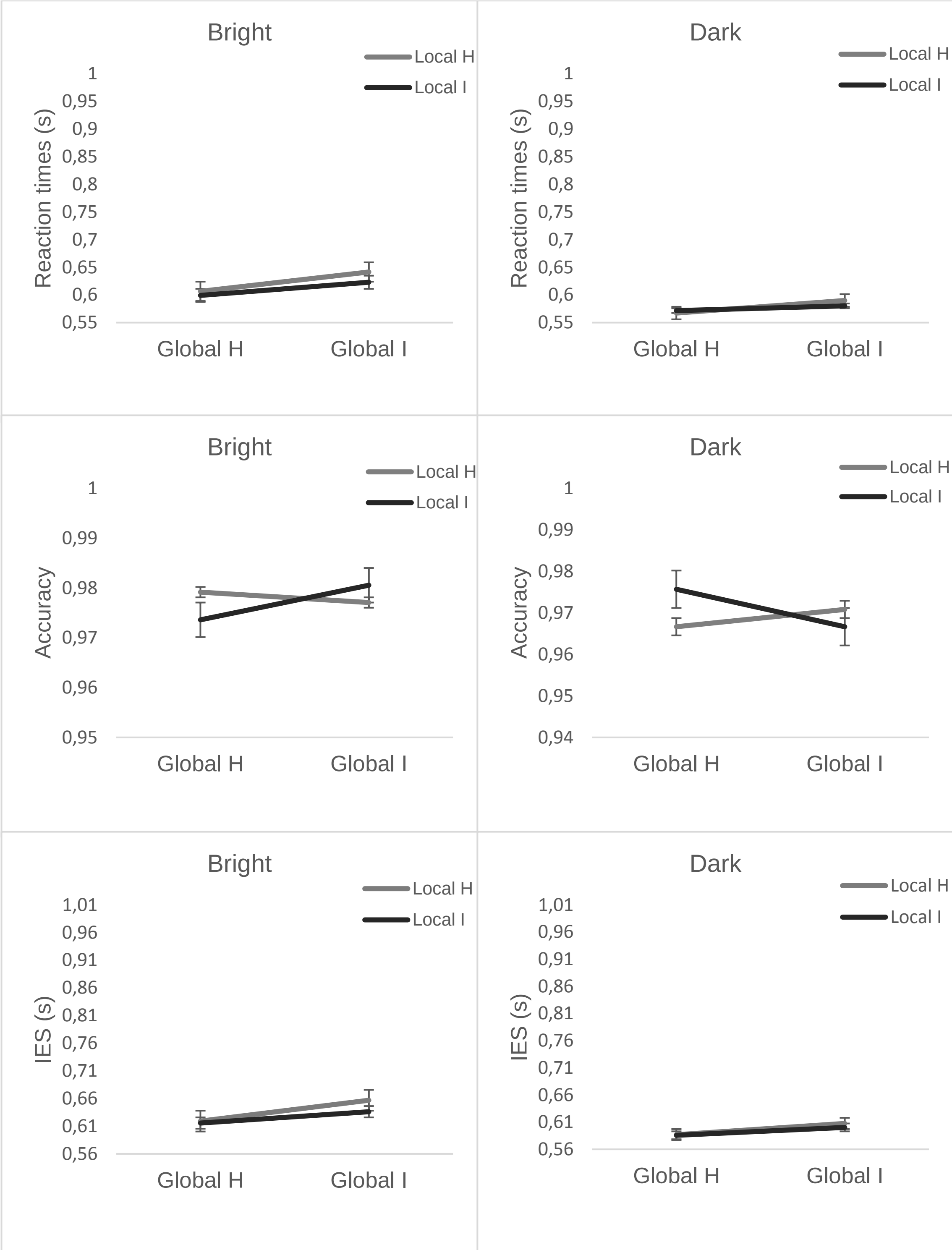


Figure 16: Results of the second-highest luminance contrast experiment (local level)
Experiment 2: Participants responded faster to dark dots and to a global H. For global I, participants responded additionally faster to a local I. For a global I, participants were more accurate for bright dots, independent of the local letter, whilst for a global H, participants were only more accurate for bright dots if the local letter was also an H. Therefore, for global I, a speed-accuracy trade-off occurred. Participants performed better for dark dots, for a global H and for a local I.

Reaction times

The main effect of luminance was significant, $F(1,19)=63.137$, $p<.001$, $\eta^2_p=.769$. Participants responded faster to dark (M:0.577, SD:0.063) than to bright dots (M:0.618, SD:0.067). The main effect of global letter was also significant, $F(1,19)=62.405$, $p<.001$, $\eta^2_p=.767$, with participants responding faster to H (M:0.586, SD:0.067) than to I (M:0.609, SD:0.067). The main effect of local letter was significant as well, $F(1,19)=11.368$, $p=.003$, $\eta^2_p=.374$. Participants responded faster when the local letter was an I (M:0.594, SD:0.063) than when it was an H (M:0.601, SD:0.067). The interactions luminance x global letter, $F(1,19)=6.852$, $p=.017$, $\eta^2_p=.265$, luminance x local letter, $F(1,19)=6.854$, $p=.017$, $\eta^2_p=.265$, and global letter x local letter, $F(1,19)=7.253$, $p=.014$, $\eta^2_p=.276$, were also significant. The interaction global letter x local letter showed that only for the letter I, participants responded faster when the global and local letter matched. This was not the case for the letter H. The interaction luminance x global letter x local letter was not significant. To further examine the significant interactions, simple effect analyses were conducted on global H and I separately.

For global H, there was a significant main effect of luminance, $F(1,19)=42.814$ $p<.001$, $\eta^2_p=.693$. Participants responded faster to dark (M:0.569, SD:0.067) than to bright (M:0.603, SD:0.067) dots.

For global I, the main effect of luminance was significant, $F(1,19)=56.862$, $p<.001$, $\eta^2_p=.750$. Participants responded faster to dark (M:0.585, SD:0.063) than to bright dots (M:0.632, SD:0.072). The main effect of local letter was significant as well, $F(1,19)=13.529$, $p=.002$, $\eta^2_p=.416$, with participants being faster when the local letter was an I (M:0.602, SD:0.067) than when it was an H (M:0.616, SD:0.067).

Accuracy

The main effect of luminance was significant, $F(1,19)=6.449$, $p=.020$, $\eta^2_p=.253$. Participants were more accurate for bright (M:0.978, SD:0.179) than for dark dots (M:0.970, SD:0.179), which means that there was a speed-accuracy trade-off. The main effect of global letter, $F(1,19)<.001$, $p=1.000$, $\eta^2_p<.001$, and of local letter, $F(1,19)=.034$, $p=.856$, $\eta^2_p=.002$, were not significant. The interaction global letter x local letter x luminance was significant as well, $F(1,19)=7.217$, $p=.015$, $\eta^2_p=.275$. None of the other interaction were significant. To further examine the significant interaction, simple effect analyses were conducted on global H and I separately.

For global H, there was a significant interaction local letter x luminance, $F(1,19)=5.743$, $p=.027$, $\eta^2_p=.232$. To further examine this interaction, a t-test was conducted on bright vs. dark dots for local H and local I separately. It was significant for local H, $t(19)=2.392$, $p=.027$, with participants being more accurate for bright (M:0.979, SD:0.022) than for dark dots (M:0.967, SD:0.033).

For global I, there was a significant main effect of luminance, $F(1,19)=6.832$, $p=.017$, $\eta^2_p=.262$, with participants being more accurate for bright (M:0.979, SD:0.179) than for dark dots (M:0.969, SD:0.179). Therefore, there were speed-accuracy trade-offs for both global H and global I.

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The main effect of luminance was significant, $F(1,19)=45.962$, $p<.001$, $\eta^2_p=.708$. Participants showed better performance for dark dots (M:0.595, SD:0.063) than for bright dots (M:0.632, SD:0.072). The main effect of global letter was significant as well, $F(1,19)=34.369$, $p<.001$, $\eta^2_p=.644$. Participants performed better for a global H (M0.602, SD:0.063) than for a global I (M:0.625, SD:0.067). The main effect of local letter was also significant, $F(1,19)=5.182$, $p=.035$, $\eta^2_p=.214$, with participants performing better for a local I (M:0.609, SD:0.067) than for a local H (M:0.618, SD:0.067). None of the interactions were significant.

3.3.3 Discussion

Like in experiment 1, participants performed better for dark dots and for a global H. A new finding of this experiment was that participants also performed better for a local I than for a local H. This effect of letter is more difficult to explain than the luminance effect. It can be said that the letter I looks more atypical than the letter H, so the assumption could be made that this influenced performance, although it was only the case on the local level. However, previous research has shown that generally, typical targets facilitate performance (e.g. Maxfield et al., 2014; Rosch et al., 1976), so it is possible that better performance for a local I just occurred due to chance.

Importantly, in this experiment, matching conditions did not lead to better performance and mismatching conditions did not cause worse performance. It is possible that due to the local level focus of this series of experiments, participants narrowed their attentional focus down to the local letter where the dot was embedded. This might have prevented them from taking the whole global letter into account (Gaspar, & Clore, 2002; Huntsinger et al., 2010) and therefore, a match or mismatch of the global and the local level did not have any effects. The time-course prediction of interference effects according to the cognitive control theory does not really explain the lack of interference effects in this experiment. It could only serve as one explanation if we assume that automatic instead of controlled processing took place throughout the whole experiment, possibly due to the relatively high luminance contrast. However, the bottleneck theory could serve as an alternative explanation: responses to dark dots trended to be faster than to both global letters, but in turn the responses to the letters trended to be faster than responses to bright dots. Therefore, it is possible that the processes of luminance response and letter processing did not happen simultaneously, which in turn prevented the occurrence of interference effects. However, it has to be mentioned that faster vs. slower responses for dots and letters were not statistically significant. Nevertheless, this provided the rationale for carrying out another experiment with less luminance contrast between the dots. It was predicted that less luminance contrast would lead to less differences in response times between bright and dark dots and this in turn might lead to the occurrence of interference effects in the Navon stimuli.

3.4 Experiment 3: Second-least luminance contrast

There were no interference effects for the last experiment. It was concluded that the relatively high luminance contrast between bright and dark dots prevented the occurrence of interference effects. According to the bottleneck theory, less luminance contrast between bright and dark dots might bring the processes of responding to the luminance and letter processing closer together in time. In line with the cognitive control theory, overall slower RTs (induced by less luminance contrast between the dots) might lead to a clearer distinction between automatic and controlled processes within this experiment. This provided the rationale for carrying out another experiment with less luminance contrast between the dots.

3.4.1 Methods

Participants

25 students from the University of Birmingham took part in the experiment in exchange for course credits or monetary compensation. The inclusion criteria were normal or corrected-to-normal vision and normal colour vision. The mean age was 19.08 years (SD:0.81), 21 participants were female, and 21 participants were right-handed.

Stimuli, Procedure, Design and Analysis

The experimental stimuli, procedure, design and analysis were the same as in experiments 1 and 2, apart from that this time the luminance difference between bright (RGB values: 182) and dark (RGB values: 108) dots was further reduced. The luminance values in this experiment corresponded to the luminance values of experiment 2 in chapter 2. The exclusion criterion was again accuracy lower than 95% and according to this criterion, 5 participants had to be excluded from the analysis. The outlier removal procedure was the same as in the previous experiments and according to this, all trials with RTs higher than 1.25 s and lower than 0.11 s were excluded.

3.4.2 Results

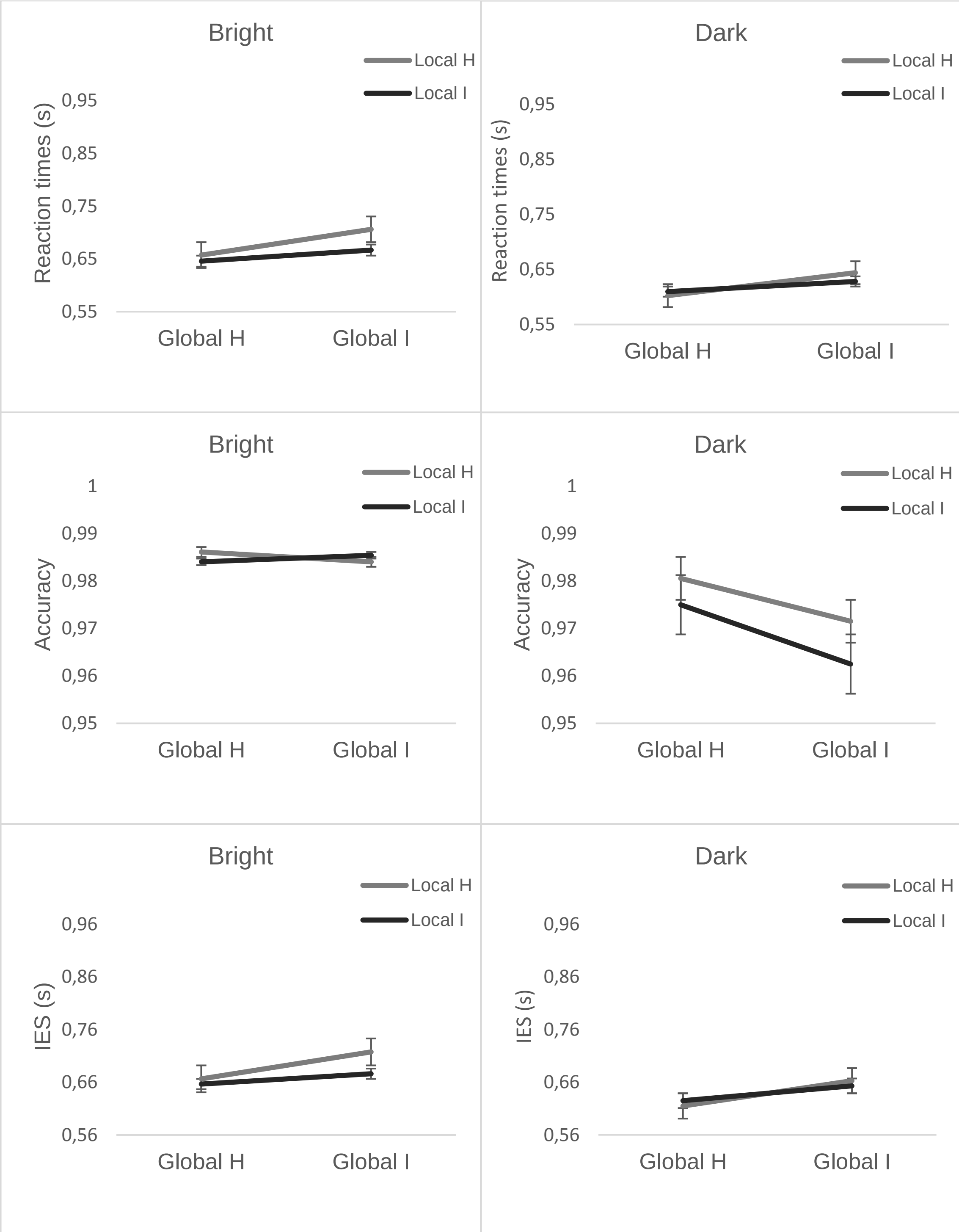

Figure 17: Results of the second-least luminance contrast experiment (local level)
Experiment 3: Participants responded faster for dark dots. For global I, participants additionally responded faster to a local I. Participants were more accurate for bright dots, which means that there was a speed-accuracy trade-off. Participants performed better for a global H and for dark dots. When the dots were bright, participants additionally performed better for a local I.

Reaction times

The main effect of luminance was significant, $F(1,19)=37.346$, $p<.001$, $\eta^2_p=.663$. Participants responded faster to dark (M:0.621, SD:0.085) than to bright dots (M:0.669, SD:0.089). There was also a significant main effect of global letter, $F(1,19)=115.769$, $p<.001$, $\eta^2_p=.859$. Participants responded faster to global H (M:0.629, SD:0.085) than to global I (M:0.661, SD:0.085). The main effect of local letter was also significant, $F(1,19)=33.197$, $p<.001$, $\eta^2_p=.636$. Participants responded faster when the local letter was an I (M0.638, SD:0.085) than when it was an H (M:0.652, SD:0.085). The interactions luminance x local letter, $F(1,19)=24.596$, $p<.001$, $\eta^2_p=.564$, and global letter x local letter, $F(1,19)=29.041$, $p<.001$, $\eta^2_p=.605$, were also significant. The interaction global letter x local letter showed that only for the letter I, participants responded faster when the global and local letter identity matched. This was not the case for the letter H. None of the other interactions were significant. To further examine the significant interactions, simple effect analyses were conducted for both global H and I separately.

For global H, there was a main effect of luminance, $F(1,19)=28.110$, $p<.001$, $\eta^2_p=.597$. Participants responded faster to dark (M:0.606, SD:0.013) than to bright dots (M:0.651, SD:0.01). There was also a significant interaction local letter x luminance, $F(1,19)=5.349$, $p=.032$, $\eta^2_p=.220$. To further examine this interaction, a t-test was carried out to compare the local H vs. local I for bright and dark dots separately. There were no significant effects of local letter neither for bright nor for dark dots.

For global I, there was also a significant main effect of luminance, $F(1,19)=65.224$, $p<.001$, $\eta^2_p=.650$. Participants responded faster to dark (M:0.636, SD:0.085) than to bright dots (M:0.655, SD:0.089). There was also a significant main effect of local letter, $F(1,19)=67.528$, $p<.001$, $\eta^2_p=.780$. Participants responded faster when the local letter was an I (M:0.647, SD:0.085) than when it was an H (M:0.675, SD:0.085). Finally, the interaction luminance x local letter was significant as well, $F(1,19)=13.882$, $p=.001$, $\eta^2_p=.422$. To further examine this interaction, a t-test was carried out to compare the effects of local I vs. local H for bright and dark dots separately. There was a significant effect of local letter for both luminance levels. For bright I ($t(19)=-8.540$, $p<.001$), participants responded faster when the local letter was an I (M:0.667, SD:0.092) than when it was an H (M:0.706, SD:090). For dark I (t(19) -3.437, p=.003), participants responded also faster when the local letter was an I (M:0.629, SD:0.084) than when it was an H (M:0.643, SD:0.089).

Accuracy

There was a significant main effect of luminance, F(1,19)=8.108, p=.010, η^2_p=.299. Participants were more accurate for bright (M:0.985, SD:0.009) than for dark dots (M:0.978, SD:0.018). As participants were also slower for bright dots, there was a speed-accuracy trade-off. The main effects of global letter, F(1,19)=.004, p=.947, η^2_p<.001, and of local letter, F(1,19)=.490, p=.492, η^2_p=.025, were not significant. None of the interactions was significant.

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The main effect of luminance was significant, F(1,19)=22.374, p<.001, η^2_p=.541. Participants performed better for dark (M:0.639, SD:0.080) than for bright dots (M:0.679, SD:0.089). The main effect of global letter was also significant, F(1,19)=148.475, p<.001, η^2_p=.887. Participants performed better for a global H (M:0.641, SD:0.085) than for a global I (M:0.678, SD:0.085). The main effect of local letter was significant as well, F(1,19)=11.100, p=.004, η^2_p=.369. Participants' performance was better for a local I (M:0.653, SD:0.085) than for a local H (M:0.665, SD:0.085). The interactions luminance x local letter, F(1,19)=19.601, p<.001, η^2_p=.510, and global letter x local letter, F(1,19)=19.601, p<.001, η^2_p=.508, were also significant. None of the other interactions were significant. To further examine the significant interactions, simple effect analyses were conducted for both global H and I separately.

For global H, there was a significant main effect of luminance, F(1,19)=19.603, p<.001, η^2_p=.508. Participants performed better for dark (M:0.620, SD:0.080) than for bright dots (M:0.662, SD:0.094).

For global I, the main effect of luminance was significant, F(1,19)=14.700, p<.001, η^2_p=.436. Participants performed better for dark (M:0.658, SD:0.085) than for bright dots (M:0.697, SD:0.089). The main effect of local letter was significant as well,

$F(1,19)=23.587$, $p<.001$, $\eta^2_p=.554$. Participants' performance was better for a local I (M:0.665, SD:0.085) than for a local H (M:0.690, SD:0.085). Finally, the interaction luminance x local letter was significant, $F(1,19)=12.543$, $p=.002$, $\eta^2_p=.398$. To further examine this interaction, simple effect analyses were done for local I vs. H for bright and dark dots separately. There was a significant effect of local letter for bright dots, $t(19)=6.765$, $p<.001$. Participants performed better for a local I (M:0.676, SD:0.090) than for a local H (M:0.718, SD:0.091).

3.4.3 Discussion

Like in the previous two experiments, participants performed better for dark dots and for a global H. Additionally, interference effects occurred for a bright global I, partly replicating results from experiment 1. This interference effect might have occurred due to the specific characteristics of the letter I. It could also be assumed that a bottleneck effect occurred for the letter I but not for the letter H, which might have been due to the different response times for both global letters. However, this would not explain the lack of interference effects for a dark I. Therefore, experiments that investigated the time-course of SSC and SRC explain this result best, as those experiments showed that interference effects increase with longer responses (Bub et al., 2006; Cohen et al., 1990; Glaser, & Glaser, 1982, van Zoest et al., 2012). This effect occurred in this experiment as well, because interference effects did not occur for conditions with rather fast (i.e. bright and dark H and dark I) but only for the condition with rather slow responses (i.e. bright I). This is in contrast to the cognitive control theory, which predicts interference effects for conditions with rather fast responses within an experiment (Bialystok et al., 2004; Coderre, & van Heuven, 2014; Jansma et al., 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984; Shiffrin, & Schneider, 1977; Stuss et al., 2001; White et al., 2018).

A last experiment with even less luminance contrast was conducted in order to establish whether a match of the global and local level only facilitates performance for a bright global I, i.e. for generally worse performance or whether the same effects can be also found for a global H or a dark global I. It was predicted that even less luminance contrast between the dots would abolish any differences in response times for bright and dark dots.

3.5 Experiment 4: Least luminance contrast

In the previous experiment, interference occurred, but it was only the case for a bright I, where performance was generally worse. In order to find out whether a reduction of luminance contrast between the dots generally leads to an interference effect, but only for specific letters, or whether more reduction in luminance contrast might lead to interference effects in other conditions than just a bright I, a last experiment with the least luminance contrast between the dots was conducted.

3.5.1 Methods

Stimuli, Procedure, Design and Analysis

The experimental stimuli, procedure, design and analysis were the same as in the previous experiments, apart from that this time the luminance difference between bright (RGB values: 176) and dark (RGB values: 129) dots was further reduced. The luminance values in this experiment corresponded to the luminance values of experiment 3 in chapter 2. The exclusion criterion was again accuracy lower than 95%. Outlier removal was based on the same criteria as before and according to this, all trials with RTs higher than 1.54 s were excluded from the analysis.

3.5.2 Results

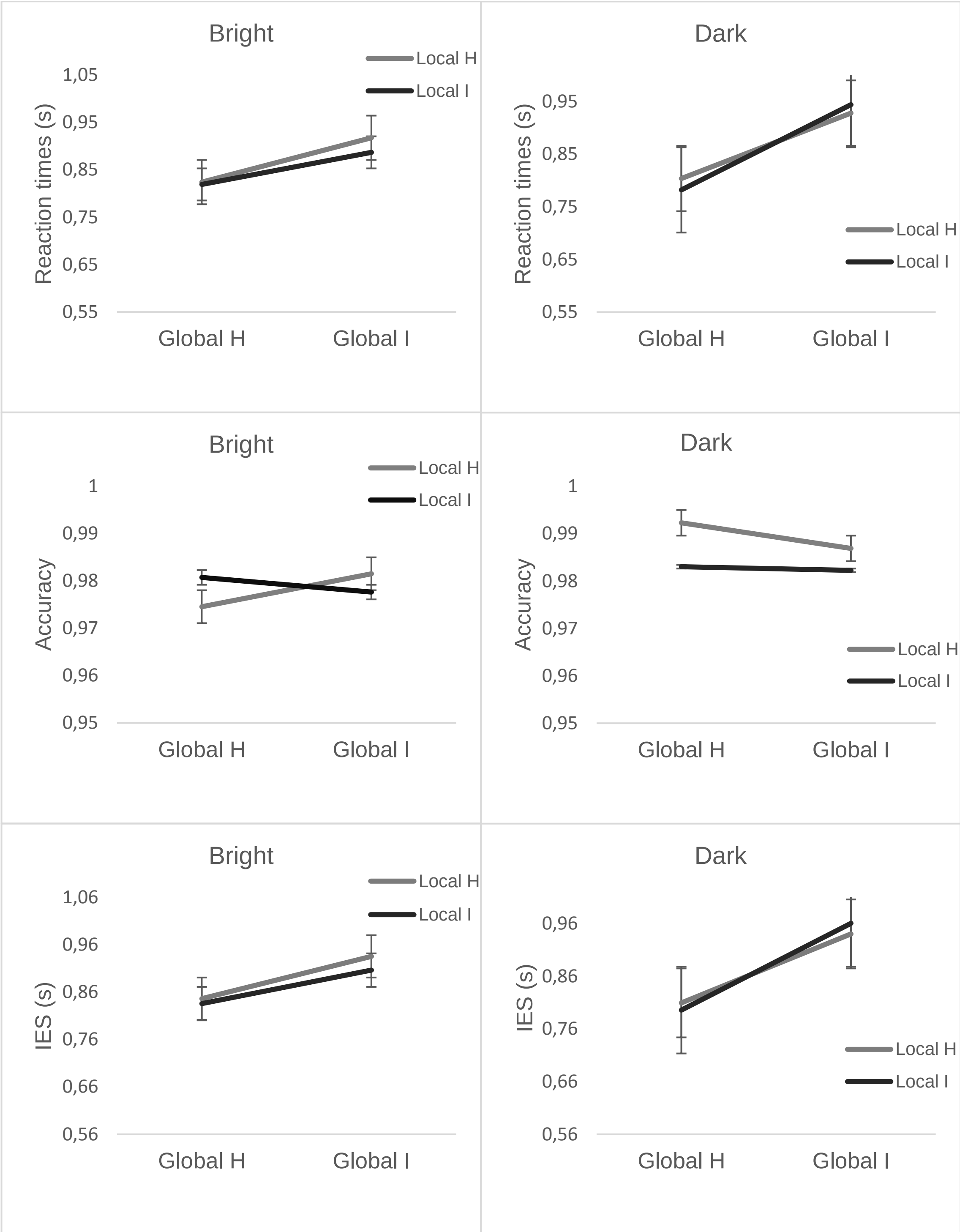

Figure 18: Results of the least luminance contrast experiment (local level)
Experiment 4: Participants responded faster to a global H. For global H, participants responded faster to dark dots and to a local I. For global I, participants responded faster to bright dots and for bright global I, they also responded faster to a local I. Participants were more accurate for dark dots. There was no speed-accuracy trade-off. Participants performed better for a global H. For global H, participants performed better for dark dots and for a local I. For global I, participants performed better for bright dots and for bright I, they performed better for a local I.

Reaction times

The main effect of global letter was significant, $F(1,17)=118.156$, $p<.001$, $\eta^2_p=.874$. Participants responded faster to a global H (M:0.807, SD:0.093) than to a global I. The main effect of local letter was also significant, $F(1,17)=5.961$, $p=.026$, η2p=.260, with participants responding faster to a local I (M:0.858, SD:0.098) than to a local H(M:0.868, SD:0.093). The main effect of luminance was not significant, $F(1,17)=.078$, $p=.784$, $\eta^2_p=.005$. The interactions luminance x global letter, $F(1,17)=38.797$, $p<.001$, $\eta^2_p=.695$, and luminance x global letter x local letter, $F(1,17)=9.221$, $p=.007$, $\eta^2_p=.352$, were also significant. No other interactions were significant. To further examine the significant interactions, simple effect analyses were conducted for both global H and I separately.

For global H, the main effect of luminance was significant, $F(1,17)=6.666$, $p=.019$, $\eta^2_p=.282$. Participants responded faster to dark dots (M:0.793, SD:0.093) than to bright dots (M:0.822, SD:0.118). The main effect of local letter was also significant, $F(1,17)=9.900$, $p=.006$, $\eta^2_p=.368$, with participants responding faster to a local I (M:0.801, SD:0.089) than to a local H (M:0.814, SD:0.098). The interaction was not significant.

For global I, the main effect of luminance was significant. $F(1,17)=13.412$, $p=.002$, $\eta^2_p=.441$. This time, participants responded faster to bright (M:0.902, SD:0.106) than to dark dots (M:0.936, SD:0.102). The interaction luminance x local letter was significant as well, $F(1,17)=9.405$, $p=.007$, $\eta^2_p=.356$. To further examine this interaction, simple effect analyses were conducted for local I vs. local H for bright and dark dots separately. It was significant for bright dots, $t(17)=3.188$, $p=.005$, with participants responding faster to a local I (M:0.887, SD:0.113) than to a local H (M:0.918, SD:0.102).

Accuracy

There was a significant main effect of luminance, $F(1,17)=6.456$, $p=.021$, $\eta^2_p=.275$. Participants were more accurate for dark (M:0.986, SD:0.016) than for bright dots (M:0.979, SD:0.022). As they were also faster for dark dots, there was no speed-accuracy trade-off. The main effects of global letter, $F(1,17)=.058$, $p=.813$, $\eta^2_p=.003$, and local letter, $F(1,17)=2.576$, $p=.127$, $\eta^2_p=.132$, were not significant. None of the interactions were significant either.

IES

The main effect of global letter was significant, $F(1,17)=125.670$, $p<.001$, $\eta^2_p=.881$. Participants performed better for global H (M:0.822, SD:0.093) than for global I (M:0.936, SD:0.102). The main effect of local letter was also significant, $F(1,17)=5.546$, $p=.031$, $\eta^2_p=.246$. This time, participants performed better for local I (M:0.875, SD:0.093) than for local H (M:0.883, SD:0.098). The main effect of luminance was not significant, $F(1,17)=.171$, $p=.684$, $\eta^2_p=.010$. The interactions luminance x global letter, $F(1,17)=31.310$, $p<.001$, $\eta^2_p=.684$ and luminance x global letter x local letter, $F(1,17)=5.863$, $p=.027$, $\eta^2_p=.256$, were significant. None of the other interactions were significant. To further examine the significant interactions, simple effect analyses were conducted for global H and I separately.

For global H, there was a significant main effect of luminance, $F(1,17)=7.116$, $p=.026$, $\eta^2_p=.258$. Participants performed better for dark (M:0.803, SD:0.093) than for bright dots (M:0.841, SD:0.106). The main effect of local letter was also significant, $F(1,17)=5.923$, $p=.016$, $\eta^2_p=.295$, with participants performing better for a local I (M:0.816, SD:0.089) than for a local H (M:0.828, SD:0.098). The interaction was not significant.

For global I, the main effect of luminance was also significant, $F(1,17)=10.312$, $p=.005$, $\eta^2_p=.378$. This time, participants performed better for bright (M:0.921, SD:0.106) than for dark dots (M:0.950, SD:0.102). The main effect of local letter was not significant, $F(1,17)=.312$, $p=.584$, $\eta^2_p=.378$. However, the interaction luminance x local letter was significant, $F(1,17)=15.464$, $p=.001$, $\eta^2_p=.476$. To further examine this interaction, t-tests were conducted for local I vs. local H for bright and dark dots separately. The t-test was significant for bright dots, $t(17)= -3.706$, $p=.002$, with participants better performing for a local I (M:0.906, SD:0.107) than for a local H (M:0.935, SD:0.098).

3.5.3 Discussion

Like in all previous experiments, participants performed better for a global H. In addition, participants performed better for a local I. Importantly, this effect occurred for both global H and global I. Better performance for a local I when the global letter was an H does not match our predictions, considering that generally, participants are faster and perform better when the global and the local level are congruent, especially when participants attend to the local level (e.g. Kimchi, & Palmer, 1982; Martin, 1979; Navon, 1977; 1981). For a global I however, the predicted typical interference effect occurred: participants performed better when global and local letter identity matched. However, this was only the case for bright dots. It is difficult to explain this result with the bottleneck theory, especially because according to the predicted reverse U-shape function, no interference effects should have occurred for this low luminance contrast condition (e.g. Pashler, & Johnston, 1988). This result also contradicts the cognitive control theory, according to which responses should occur for fast but not for slow responses (Bialystok et al., 2004; Coderre, & van Heuven, 2014; Jansma et al., 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984; Shiffrin, & Schneider, 1977; Stuss et al., 2001; White et al., 2018). However, the interference effect which occurred in this experiment matches with the results of studies that showed that interference effects can be greater for slower responses (Bub et al., 2006; Cohen et al., 1990; Glaser, & Glaser, 1982; van Zoest et al., 2012). Although participants responded faster to a bright I than to a dark I, and interference effects only occurred for a bright I, participants responded slower to global I than to global H and interference effects did not occur for a global H. The most plausible explanation for the results in this experiment could be that for some reason performance is much better for the letter I than for the letter H when attention is directed to the local level, and this finding outstands the typical finding of better performance if the global and the local level match. This might explain the better performance for a local I even when the global letter is different, i.e. a global H in this experiment. It can also be assumed that in this series of experiments, participants might not have taken the whole global letter into account but they might have narrowed down their attentional focus to the local letter, where the dot was embedded. However, all the possible explanations do not provide an answer to the question why participants performed better for a local I than for a local

H, especially because previous research suggests that performance is generally better for typical targets (e.g. Maxfield et al., 2014; Rosch et al., 1976) and the letter H can be seen as more typical than the letter I. In contrast to the other experiments, there was no significant main effect of luminance anymore, which can be explained by the fact that the luminance contrast of the dots was the smallest in this experiment, which made the dark dots less outstanding. To compare all experiments together, a between-experiments analysis was conducted.

3.5.4 Between-experiments analysis

To compare the different conditions (luminance, global letter and local letter) across all four experiments together and to increase power, a between-experiments analysis was conducted. The aim was to establish if faster responses to matching conditions are linked to rather slow responses/ worse performance, as it could be concluded from the results of experiment 1, 3 and 4.

3.5.4.1 Methods

A mixed ANOVA with the within-subjects factors luminance (bright or dark), global letter (H or I) and local letter (H or I) and the between-subject factor experiment (1-4) was conducted on IES (in s).

3.5.4.2 Results

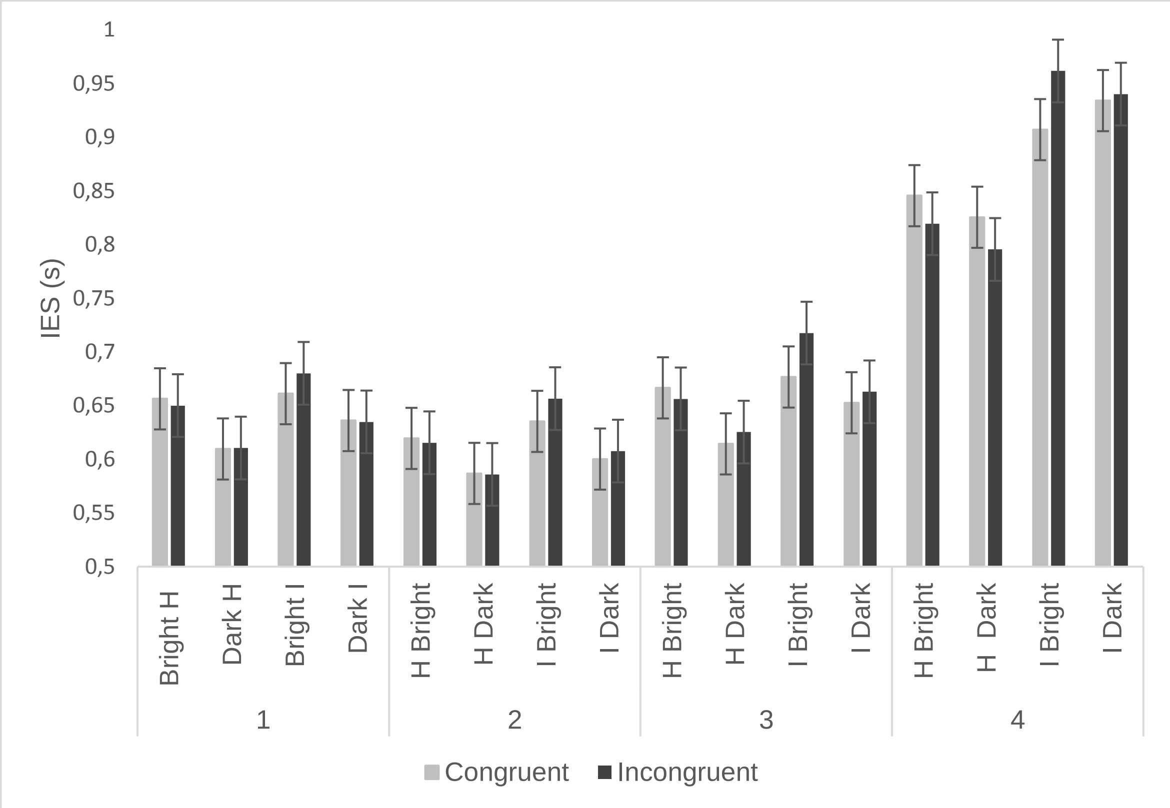

Figure 19: Illustration of all local level experiment results
Illustration of RTs for all four experiments and the different conditions (bright and dark letters, congruent and incongruent global H and I).

IES

The main effect of luminance was significant, $F(1,74)=57.624$, $p<.001$, $\eta^2_p=.438$. Participants performed better for dark (M:0.683, SD:0.079) than for bright dots (M:0.713, SD:0.088). The main effect of global letter was also significant, $F(1,74)=291.483$, $p<.001$, $\eta^2_p=.798$. Participants performed better for a global H (M:0.674, SD:0.079) than for a local I (M:0.723, SD:0.088). The main effect of local letter was significant as well, $F(1,74)=18.680$, $p<.001$, $\eta^2_p=.202$. Participants' performance was better for a local I (M:0.694, SD:0.088) than for a local H (M:0.703, SD:0.088). Finally, the main effect of experiment was significant, $F(3,74)=39.211$, $p<.001$, $\eta^2_p=.614$. Participants performed best for experiment 2 (second-highest luminance contrast, M:0.614, SD:0.167), second-best for experiment 1 (highest luminance contrast, M:0.642, SD:0.167), second-worst for experiment 3 (second-least luminance contrast (M:0.659, SD:0.167) and worst for experiment 4 (least luminance contrast (M:0.879, SD:0.173).

The interaction luminance x experiment was significant, $F(3,74)=4.493$, $p=.006$, $\eta^2_p=.154$. For all experiments apart from experiment 4 participants performed better for dark dots. The interaction global letter x experiment was also significant, $F(3,74)=55.764$, $p<.001$, $\eta^2_p=.693$. For all experiments, participants performed better for a global H, but there were differences between the individual experiments in the strength of this effect. Further significant interactions were luminance x global letter, $F(1,74)=14.785$, $p<.001$, $\eta^2_p=.167$, luminance x global letter x experiment, $F(3,74)=15.550$, $p<.001$, $\eta^2_p=.387$, luminance x local letter, $F(1,74)=17.446$, $p<.001$, $\eta^2_p=.191$, global letter x local letter, $F(1,74)=6.662$, $p=.012$, $\eta^2_p=.083$, global letter x local letter x experiment, $F(3,74)=3.725$, $p=.015$, $\eta^2_p=.131$ and luminance x global letter x local letter, $F(1,74)=7.610$, $p=.007$, $\eta^2_p=.093$. The other interactions were not significant. To further examine the significant interactions, simple effect analyses were conducted on global H and I separately.

For a global H, there was a significant main effect of luminance, $F(1,74)=65.398$, $p<.001$, $\eta^2_p=.469$. Participants performed better for dark (M:0.655, SD:0.079) than for bright dots (M:0.693, SD:0.088). The main effect of experiment was significant as well, $F(3,74)=26.837$, $p<.001$, $\eta^2_p=.521$. Participants performed best for experiment 2 (second-highest luminance contrast, M:0.602, SD:0.167), second-best for experiment 1 (highest luminance contrast, (M:0.631, SD:0.167), second-worst for experiment 3 (second-least luminance contrast, M:0.641, SD:0.167) and worst for experiment 4 (least luminance contrast (M:0.822, SD:0.173). The main effect of local letter was not significant, $F(1,74)=3.308$, $p=.078$, $\eta^2_p=.043$. None of the interactions were significant.

For a global I, the main effect of luminance was significant, $F(1,74)=25.862$, $p<.001$, $\eta^2_p=.259$. Participants performed better for dark (M:0.712, SD:0.088) than for bright dots (M:0.734, SD:0.088). The main effect of local letter was also significant, $F(1,74)=19.494$, $p<.001$, $\eta^2_p=.209$. Participants performed better for a local I (M:0.716, SD:0.088) than for a local H (M:0.729, SD:0.088). Finally, the main effect of experiment was significant, $F(3,74)=51.364$, $p<.001$, $\eta^2_p=.676$. Participants performed best for experiment 2 (second-highest luminance contrast, M:0.625, SD:0.167), second-best for experiment 1 (highest luminance contrast, M:0.653, SD:0.167), second-worst for experiment 3 (second-least luminance contrast, M:0.678, SD:0.167) and worst for experiment 4 (least luminance contrast, M:0.936, SD:0.173). The interaction luminance x experiment was significant, $F(3,74)=15,377$, $p<.001$, $\eta^2_p=.460$. For all experiments apart from experiment 4 (least luminance contrast) participants performed better when the dots were dark. Finally, the interaction luminance x local letter was significant, $F(1,74)=25.944$, $p<.001$, $\eta^2_p=.260$. None of the other interactions were significant. To further examine the significant interactions and look at the effects of local letters, simple effect analyses were conducted on bright and dark global I separately.

For a bright global I, the main effect of local letter was significant, $F(1,74)=49.511$, $p<.001$, $\eta^2_p=.401$. Participants performed better when the local letter was an I (M:0.720, SD:0.097) than when it was an H (M:0.747, SD:0.088). The main effect of experiment was significant as well, $F(3,74)=36.012$, $p<.001$, $\eta^2_p=.594$. Participants performed best for experiment 2 (second-highest luminance contrast, M:0.646, SD:0.177), second-best for experiment 1 (highest luminance contrast. M:0.671, SD:0.177), second-worst for experiment 3 (second-least luminance contrast (M: 0.697, SD:0.177) and worst for experiment 4 (least luminance contrast (M:0.921, SD:0.185). The interaction was not significant.

For a dark global I, there was no significant main effect of local letter, $F(1,74)=.054$, $p=.817$, $\eta^2_p=.001$. However, the main effect of experiment was significant, $F(3,74)=65.084$, $p<.001$, $\eta^2_p=725$. Participants performed best for experiment 2 (second-highest luminance contrast, M:0.604, SD:0.167), second-best for experiment 1 (highest luminance contrast. M:0.635, SD:0.167), second-worst for experiment 3 (second-least luminance contrast (M:0.658, SD:0.167) and worst for experiment 4 (least luminance contrast (M:0.950, SD:0.173). The interaction was not significant.

3.5.4.3 Discussion

Generally, there were many interactions with experiment, making it difficult to draw general conclusions for all four experiments together. However, some results were consistent or mostly consistent. For example, participants performed better for dark dots, which can be explained by the fact that the dots were presented against a white background, which made the dark dots more outstanding. Previous research suggests that performance is generally better for dark stimuli and for a high luminance contrast (Buchner, & Baumgartner, 2007; Komban et al., 2011; Plainis, & Murray, 2000; Walkey et al., 2006). In addition, performance was generally better for a global H, which can be explained by the fact that in this letter, the dots were embedded horizontally, whilst they were embedded vertically in a global I and previous research has found that performance is generally better on the horizontal (Collewijn, & Taminga, 1984; Ingster-Moati et al., 2009; Schmidt et al., 1993; Yu et al., 2010). Only for a global bright I, the predicted interference effect occurred. The differences in interference effects for the letters H and I were also found in the standard Navon experiment that we conducted (chapter 2, experiment 1). In this experiment, interference effects occurred on both the global and the local level for the letter H but only on the global level for the letter I. However, the results of the standard Navon experiment do not fully explain the results in this chapter, because the local letter had no effects on a global H in this series of experiments.

3.6 General discussion

This chapter aimed to investigate whether interference effects in task-irrelevant Navon stimuli occur if participants' attention is directed to the local level. Rendering the Navon stimuli task-irrelevant was operationalised by asking the participants to respond to the luminance (bright or dark) of a dot that was embedded in one of the local letters (H or I, congruent or incongruent) instead of responding to the letter itself. We predicted that participants should respond faster if the global and local level matched, even if the letters were task-irrelevant. We predicted better performance and faster responses for dark than for bright stimuli, based on previous findings (Buchner, & Baumgartner, 2007; Komban et al., 2001). This should also enable to study time-course within experiments. We used four different luminance contrast conditions for the dots, as it has been shown that decreasing the luminance contrast increases RTs (Plainis, & Murray, 2000; Walkey et al., 2006). The aim was to manipulate the speed of responses and therefore to manipulate the time-course of the predicted interference effects between experiments. Different predictions were made about the time-course when those interference effects would occur. Those predictions were the same as in the previous chapter and were made based on the cognitive control theory (Bialystok et al., 2004; Coderre, & van Heuven, 2014; Jansma et al., 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984; Shiffrin, & Schneider, 1977; Stuss et al., 2001; White et al., 2018) and the bottleneck theory (Appelbaum et al., 2012; Broadbent, 1958; Dyer, 1971; Glaser, & Glaser, 1982; Lu, & Proctor, 2001; Roelofs, 2010; Starrevald, & La Heij, 2017).

Additionally, two different predictions were made about the occurrence of interference effects considering that in this chapter, a local-level task was used. On the one hand, the predictions could remain the same as for the global level experiments (chapter 2), which means that interference effects should occur, even if the stimuli are task-irrelevant. This prediction can be made if it is assumed that despite especially when doing a local-level task, interference effects should occur (e.g. Hoffmann, 1980; Martin, 1979; Navon, 1977; 1981). On the other hand, it could be assumed that no interference effects would occur at all for this series of experiments, as previous research has also shown that in a local level task, participants do not always focus on the whole global stimulus (Gasper, & Clore, 2002; Huntsinger et al., 2010).

Participants performed better for dark than for bright dots, supporting previous findings (Buchner, & Baumgartner, 2007; Komban et al., 2001). The luminance manipulation predicting longer responses for decreasing luminance contrast (Plainis, & Murray, 2000; Walkey et al., 2006) was only partly successful, considering responses were shortest and performance was best for experiment 2, the condition with the second-highest luminance contrast.

Evidence for the cognitive control theory

The series of experiments in this chapter revealed that a match of the global and local level only facilitated performance for a bright global I, where responses trended to be slower and performance seemed to be worse than in the other conditions. It could be assumed that this condition was the most difficult and therefore might have required most cognitive resources. In turn, a match of the global and local level might have facilitated performance specifically in this condition. However, this explanation would contradict the results discussed in the previous chapter, where interference effects occurred for rather fast responses, and this was explained with the cognitive control theory as well, according to which interference effects occur for fast responses (Bialystok et al., 1004; Coderre, & van Heuven, 2014; Jansma et al., 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984; Shiffrin, & Schneider, 1977; Stuss et al., 2011; White et al., 2018). It would also contradict the perceptual load theory proposed by Lavie (1995), which states that distractors (in our case the irrelevant letters) are not processed if too many cognitive resources are required, hence in conditions where responses should be slower and performance should be worse than in other conditions. When looking at the time-course prediction of the cognitive control theory between experiments, it has to be noted that this prediction could be partly confirmed. Interference effects occurred for the experiment with the highest luminance contrast (experiment 1), although it was only the case for RTs. Additionally, the between-experiments analysis showed that responses were actually not fastest for experiment 1, a requirement which should have been met in order to explain the time-course of interference effects between experiments. Additionally, interference effects occurred for experiments with lower luminance contrast, which would contradict the time-course prediction of interference effects between experiments.

Evidence for the bottleneck theory

Looking into specific response times within experiments, it could not be confirmed that at any given time, RTs for luminance response and letter processing were overlapping. According to the bottleneck theory, interference would have occurred in this scenario. The results of this series of experiments also do not confirm the reversed U-shaped function that was predicted for the bottleneck theory (Pashler, & Johnston, 1988), because according to this prediction, interference effects would not have occurred for experiments with generally high or low luminance contrasts. Although interference effects did not occur for the condition with the highest luminance contrast, they occurred for the condition with the lowest luminance contrast. Additionally, the reversed U-shaped function would predict interference effect for the other luminance contrast conditions, but no interference effects occurred for experiment 2, the condition with the second-highest luminance contrast. Furthermore, in order for the reversed U-shaped function to be tested, the luminance manipulation would have needed to be successful in the sense that responses should have been shortest for the experiment with the highest luminance contrast and increased with decreasing luminance contrast. However, this was not the case in this series of experiments. Finally, we cannot definitely say that letter processing and luminance detection happened as two independent processes, because letter processing was task-irrelevant. Therefore, it is not clear whether participants actually processed letter identity or not. Additionally, we did not manipulate the SOA interval between letter processing and luminance response.

Evidence for time-course of SSC experiments

The time-course of interference effects in our series of experiments can be best explained with experiments that looked into the time-course of Stroop stimuli and found that the Stroop effect increases with longer response times (Bub et al., 2006; Cohen et al., 1990; Glaser, & Glaser, 1982). Stroop-type stimuli and the set-up of our series of experiments both reflect SSC because of the overlap of the stimulus dimensions of global and local letter identity. Although this overlap was stronger in the series of experiments in chapter 2, where participants responded to the luminance of the whole global letter, this series of experiments reflects SSC as well, as both irrelevant letter identities overlap. The time-course of SSC could be partly replicated in this chapter, as interference effects mainly occurred for a bright I and rather not for the other conditions (i.e. bright and dark H and dark I). At the same time, responses trended to be slowest and performance was rather worse for bright I than for dark I and for both bright and dark H.

Distinction between fast and slow responses in global and local processing

One general prediction that could be confirmed was that responses in this series of experiments were generally slower than in the series of experiments in chapter 2, which supports the prediction that the local-level focus was successfully manipulated in this series of experiments, whilst they probably focused on the global level in the experiments in the previous chapter. This is in line with the global precedence theory (e.g. Navon, 1977; 1981). In addition, the slower RTs in this series of experiments support the hypothesis that this task was overall more difficult than the task in chapter 2.

The explanation of differences in interference effects in this chapter and in the previous one according to speed (interference effects for rather fast responses in chapter 2 and for rather slow responses in this chapter) is similar to the finding of Sanocki (1993): global primes were most effective in early processing, whilst local information was rather used in late processing. Although this study cannot be compared one-to-one with our series of experiments as we did not use primes, it is still relevant for the explanation of our results and the arguments about the time-course. The results from chapter 2 and this chapter suggest that in early stages of processing, interference effects are stronger when making responses on the global level, whilst in later stages of processing, interference effects are stronger when making responses on the local level. This directly yields into the RHT postulated by Hochstein and Ahissar (2002), which suggests that global processing takes places before local processing. Therefore, interference effects should happen for early stages of processing on the global level and for later stages of processing on the local level. However, those time-course effects have not been statistically tested neither in chapter 2 nor in this chapter.

Unexplained other effects

It is also possible that a match of the global and the local level only facilitates performance when the whole letter is perceived as rather atypical, considering that I can be seen as a more atypical representative than the letter H. This assumption can be strengthened by the fact that performance was generally better for the letter H, which might have outstood the typical interference effect for this letter. However, this would go against the assumption that only the local letter, where the dot was embedded, was attended. If the latter hypothesis was true, then the global letter should not have had any effects. Nevertheless, the assumption of differences between a global H and I does not have to be rejected as a whole, because the dots were embedded differently in those letters. Therefore, it is possible that the embedment of the dots drove the different performances. Another explanation for the differences in H and I could be found when we look into Gestalt grouping principles. It is not likely that the differences in both local letters occurred because of grouping by proximity, as both letters have the same spacing. However, grouping by shape similarity (e.g. Rock, & Palmer, 1990) might have occurred and it is possible that participants were more likely to group the local I's than the local H'. This might have led to a better performance for local I's, although no research could be found that supported the statement that shapes similar to the local letters we used might facilitate performance in one condition (i.e. letter I) and hinder it in the other (i.e. letter H) according to the Gestalt grouping principle of shape similarity. Additionally, it has to be mentioned that both letters H and I that were used in this series of experiments have rather similar shapes. Another explanation for the difference in the local letters could be lateral masking, which states that humans find it difficult to identify identical or similar forms in close proximity (e.g. Bouma, 1970; Mackworth, 1965; Wolford, & Hollingsworth, 1974). Lateral masking has been amongst other investigated by rotating letters. The letter I as used in this thesis could be seen as a rotated version of the letter H. Literature search gives mixed evidence about the effects of rotated letters. Huckauf et al. (1999) found that rotation of letters does not improve or impair performance In contrast, van Leeuwen and Lachmann (2004) found that participants responded faster to letters than to rotated letters, although it has to be mentioned that the rotated letters in their experiment did not corresponded to any letter of the alphabet. In comparison, the letter I that we used can be seen as the letter I, even if it is a rather atypical I. Van Leeuwen and Lachmann (2004) showed that a congruency effect occurred for rotated letters but not for normal letters. However, it is important to mention that congruency was investigated by using surrounding congruent or incongruent shapes.

It has to be noted that when a dark dot was embedded in a global I, participants responded to the luminance by pressing the letter 'm' on the computer keyboard. Similarly, participants responded to a bright dot by pressing the letter 'k'. This might have caused an unintentional SRC effect for the global I. Consequently, this might have led to the differences in the interference effect for global H and I.

However, all the explanations did not focus on the question why a match of the global and local level only facilitated performance for a bright and not for a dark I. As responses were faster to a bright I than to a dark I, the most plausible explanation could be when looking at time-course effects. It could be possible that rather slow responses facilitate performance when the global and the local level match, at least when the task is set up on the local level.

Another important point to make is that in the replication of the Navon task (chapter 2, experiment 1), interference effects occurred on both the global and the local level for the letter H, but only on the global level for the letter I. This strongly contradicts the results in this chapter, where no interference effects occurred at all for the letter H, whilst for the letter I, interference occurred on the local level, although this was only the case for bright dots.

In conclusion, it is difficult to find a definitive explanation for the inconsistent results of the experiments in this chapter. Therefore, other experiments with a local level focus were conducted in order to find out whether interference effects for a bright I only occurred due to chance, considering that this effect did not occur consistently across all four experiments.

Chapter Four: LOCAL LETTER LUMINANCE EXPERIMENTS - LETTER S

4.1 Introduction

The previous chapters investigated the processing of task-irrelevant visual information along with task-irrelevant interference effects on either the global (chapter 2) or the local level (chapter 3) by using the Navon task (Navon, 1981). On the global level, task-irrelevance was manipulated by asking participants to indicate whether the Navon letter was brighter or darker than the square where it was embedded. In contrast, on the local level, task-irrelevance was manipulated by asking participants to indicate whether a dot that was embedded in one of the local letters was brighter or darker than the letter. The local and the global level of the letters matched (congruent condition) or did not match (incongruent condition). It was assumed that despite being task-irrelevant, the typical interference effects should occur: participants would be faster for congruent letters and slower for incongruent letters (Navon, 1977; 1981; Miller, & Navon, 2002). It is important to be clear about the terminology of matching vs. mismatching and congruent vs. incongruent again. The words matching vs. mismatching rather than congruent vs. incongruent were used, as both the global and the local level of the Navon stimuli were task-irrelevant. However, when referring to the literature, it is not always possible to make a clear distinction between the different terms, therefore those words may be used interchangeably.

The aim of this chapter was to investigate the impact of letter identity on local level interference. The series of experiments in chapter 3 revealed that interference effects only occurred in a certain condition, namely for a bright I, but not for the letter H. Several explanations for this phenomenon were proposed. Some of those explanations focused on the construction of the stimuli. For example, a match or mismatch of the global and local level might affect performance if the whole global letter can be viewed as rather atypical, as it was the case for the letter I that we used. This assumption can be strengthened by the fact that performance was always better for a global H. In addition, it has to be noted that the dots were embedded horizontally for a global H and vertically for a global I, which might have caused the different performance for both global letters due to the fact that performance is generally better on the horizontal than on the vertical (e.g. Collewijn, & Taminga, 1984; Ingster-Moati et al., 2009; Schmidt et al., 1993; Yu et al., 2010). It is possible that this performance for the global letter was the main determinant of performance irrespective of the identity of local letter. This is supported by the finding that for a global H, there was no effect of local letter. It could also be assumed that interference effects only occurred for the letter I due to lateral masking or Gestalt grouping. If we look into the Gestalt grouping principle of shape similarity (e.g. Rock, & Palmer, 1990; Wertheimer, 1923), it can be assumed that participants were more likely to group the local Is to a global I, whilst the same effect did not occur for local Hs and a global H. However, no studies could be found that support the fact that grouping might occur with stimuli similar to the ones we used only in one condition (i.e. letter I) and not in the other (i.e. letter H). Another explanation for the difference in the local letters could be lateral masking, which states that humans find it difficult to identify identical or similar forms in close proximity (e.g. Bouma, 1970; Mackworth, 1965; Wolford, & Hollingsworth, 1974). Lateral masking has been investigated amongst others by looking into letter identity and here, it is important to mention that van Leeuwen and Lachmann (2004) found an interference effect for rotated letters. The letter I as used in our experiment could be seen as a rotated version of the letter H. However, all those explanations that look into differences for I and H due to the stimuli that were used lack an explanation for the absence of an interference effect in a dark I.

In order to find out whether a match of the global and local letter only facilitates performance for the letter I and not for other letters when attention is directed to the local level, a new letter S was introduced in this chapter (see figure 20). The reasoning for choosing this letter was the embedment of the dots: they were on the same horizontal level as for the letter H. In addition, the letter S as it was used in this chapter can be seen as a rather atypical representative of the alphabet, like the letter I that was used, but contrary to the letter H. The aim was to establish whether the occurrence of task-irrelevant interference effects on the local level is letter-identity dependent or dependent on the embedment of dots. In order to first test for letter-identity-dependence, the letters H and S were used in the first experiment. If interference effects occurred, this would mean that letter-identity would have stronger effects than embedment of dots. In the second experiment, the letters I and S were used (figure

22). If no interference effect occurred for S but interference effects occurred for I, this would mean that interference effects depend on embedment of dots more than letter identity (considering the assumption of typical vs. atypical letters, as both I and S are rather atypical letters). When talking about letter identity, it is also important to mention that already in the standard Navon experiment that we conducted (see chapter 2, experiment 1), there were differences between the letters H and I. However, it has to be pointed out that in this standard Navon experiment, there was only an interference effect on the local level for H and not for I. This contradicts the findings from chapter 3, where interference effects occurred for the letter I but not for H. It can therefore be assumed that letter identity affects interference effects. The analysis of the RTs was again done based on the different letters in order to find out whether different letter identity actually drives the different effects found in the previous chapter. The analysis was also split again in bright vs. dark dots, considering that dark stimuli are usually processed faster and more accurately (Buchner, & Baumgartner, 2007; Komban et al., 2001). The luminance level of the dots corresponded to the luminance level of experiment 3 in chapter 3, as this luminance level led to faster responses to congruent stimuli for a bright I, therefore matching the predictions that interference effects should occur, even if stimuli are task-irrelevant.

4.2 Experiment 1: H-S

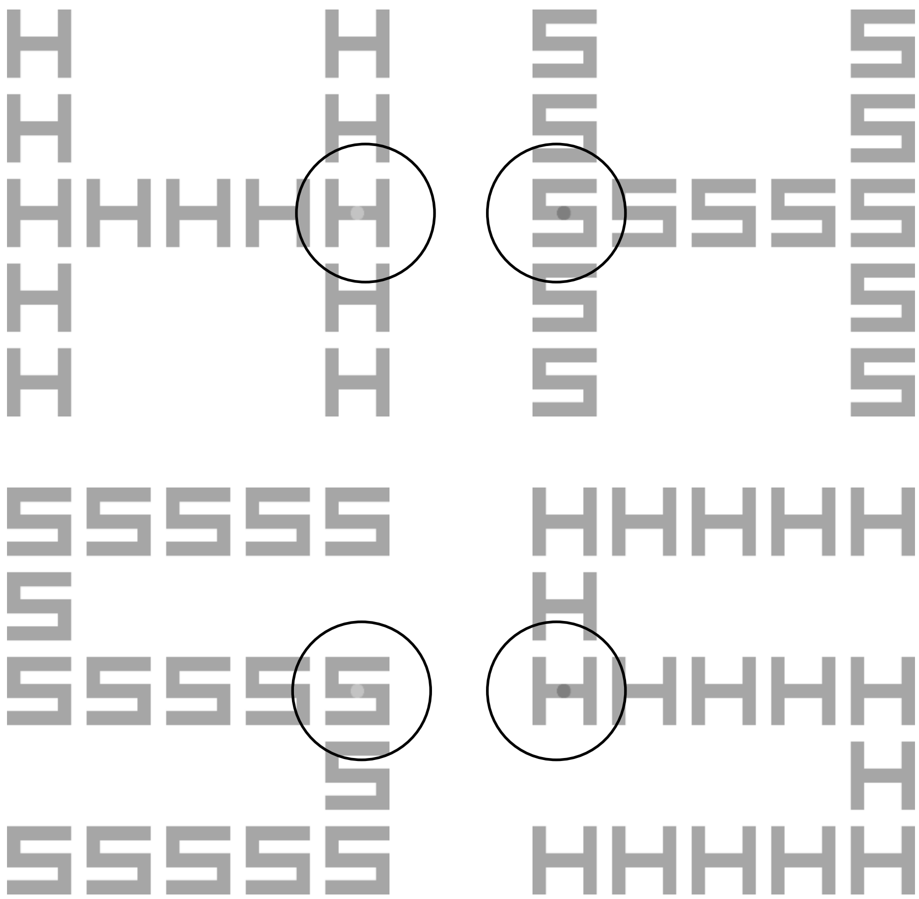

Figure 20: H-S experiment (local level)
Experiment 1: The top left image contains a bright dot embedded in a global H made up of local Hs, which means that the global and local level of the letters are the same (matching condition). The top right image is a dark dot embedded in a global H made up of local Ss, which means that the global and local level of the letters are different (mismatching condition). The bottom left image contains a bright dot embedded in a global S made up of local Ss, which means that the global and local level of the letters are the same (matching condition). The bottom right image is a dark dot embedded in a global S made up of local Hs, which means that the global and local level of the letters are different (mismatching condition).

4.2.1 Methods

Participants

26 students from the University of Birmingham took part in the experiment in exchange for course credits or monetary compensation. The inclusion criteria were normal or corrected-to-normal vision and normal colour vision. The mean age was 18.65 years (SD:0.78), all participants were female and 23 participants were right-handed.

Stimuli

A big global letter that was an H or an S (7.6°) and that was made out of smaller local letters, again H or S (1.5°), was presented in the centre of the computer screen. The letters were grey (RGB values: 149) and they were presented against a white background. If the big letter was made out of the same smaller letters (e.g. an H made out of Hs), the global and the local level matched (congruent conditions) and if the big letter was made out of different small letters (e.g. an H made out of Ss), the global and local level did not match (incongruent conditions). One of the smaller letters contained a small dot (0.3°) at the centre left or the centre right. The dot was either brighter (RGB values: 182) or darker (RGB values: 108) than its surrounding letter.

Procedure

Participants were seated 45 cm in front of a computer screen in a darkened room. Before every trial, a black fixation cross (0.9°) appeared in the centre of a black screen. After 2000 ms, the big global letter made out of smaller local letters was presented on the computer screen. Participants were asked to press the corresponding keys according to the dot brightness (k for brighter and m for darker) on the computer keyboard. The letter remained on the computer screen until participants made a response.

Design

The experiment consisted of 6 blocks with 96 trials each. Before the start of the experiment, participants were asked to complete 12 practice trials. In each block, the number of congruent and incongruent conditions and of the two different global letters balanced. The quantity of trials that contained a bright and a dark dot was equalised as well.

Analysis

A repeated measures ANOVA with the factors luminance (bright or dark), global letter (H or S) and local letter (H or S) was conducted on RTs (in s), accuracy and IES (in s) in order to account for any speed-accuracy trade-offs. The exclusion criterion was accuracy lower than 90%. 2 participants had to be excluded from the analysis according to this criterion. Outlier removal was again based on RTs higher or lower than 2 SDs from the mean and according to this criterion, all trials with RTs higher than 0.97 s and lower than 0.37 s were excluded from the analysis.

4.2.2 Results

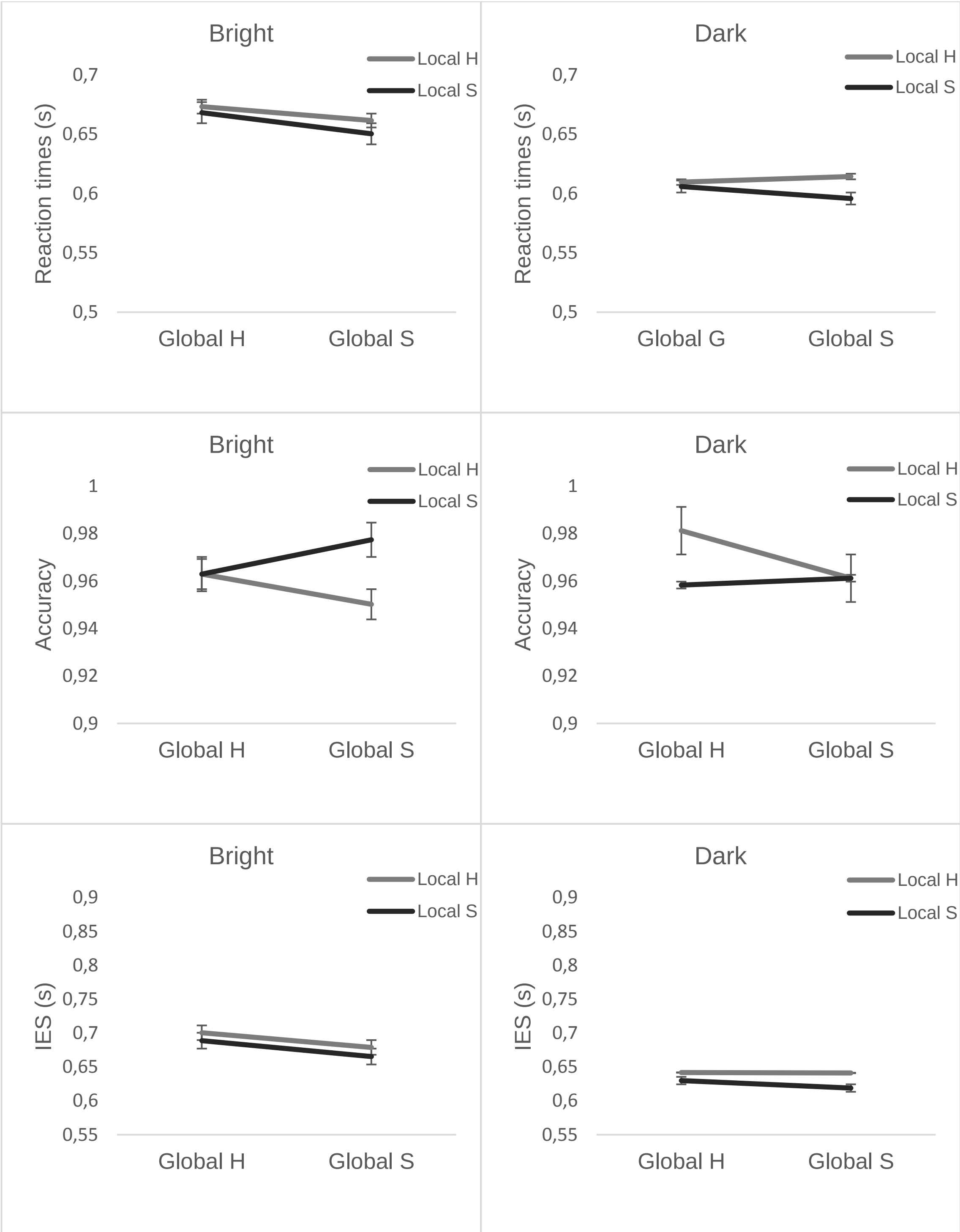

Figure 21: Results of the H-S experiment (local level)
Experiment 1: Participants responded faster to dark dots and to a local S. For bright dots, participants also responded faster to a global S. Participants were more accurate for bright dots, which means that there was a speed-accuracy trade-off. Participants were also more accurate for a global and a local S (no speed-accuracy trade-off). Participants performed better for dark dots and for a local S. For bright dots, participants also performed better for a global S.

Reaction times

There was a significant main effect of luminance, $F(1,23)=109.023$, $p<.001$, $\eta^2_p=.826$. Participants responded faster when the dots were dark (M:0.606, SD:0.065) than when they were bright (M:0.636, SD:0.073). The main effect of global letter was also significant, $F(1,23)=9.913$, $p=.004$, $\eta^2_p=.301$. Participants responded faster when the global letter was an S (M:0.631, SD:0.069) than when it was an H (M:0.639, SD:0.069). The main effect of local letter was significant as well, $F(1,23)=13.529$, $p=.001$, $\eta^2_p=.370$. Participants responded faster when the local letter was an S (M:0.630, SD:0.065) than when it was an H (M:0.640, SD:0.069). Finally, the interaction global letter x luminance was significant, $F(1,23)=6.626$, $p=.017$, $\eta^2_p=.224$. None of the other interactions were significant. To further examine the significant interaction, t-tests were completed to compare only the global letters H and S for both bright and dark dots separately.

The t-tests showed that participants only responded faster to a global S (M:0.656, SD:0.073) than for a global H (M:0.671, SD:0.074) if the dots were bright, $t(23)=3.731$, $p=.001$.

Accuracy

The main effect of luminance was significant, $F(1,23)=5.613$, $p=.027$, $\eta^2_p=.196$. Participants were more accurate for bright (M:0.972, SD:0.020) than for dark dots (M:0.958, SD:0.034). As they were also slower for bright dots, there was a speed-accuracy trade-off. The main effect of global letter was also significant, $F(1,23)=4.890$, $p=.037$, $\eta^2_p=.175$, with participants being more accurate for the letter S (M:0.968, SD:0.024) than for the letter H (M:0.962, SD:0.024). As they were also faster for a global S, there was no speed-accuracy trade-off. Finally, the main effect of local letter was significant, $F(1,23)=6.067$, $p=.022$, $\eta^2_p=.209$. Again, participants were more accurate for the letter S (M:0.968, SD:0.024) than for the letter H (M:0.962, SD:0.024). As they were also faster for a local S, there was no speed-accuracy trade-off. None of the interactions were significant.

IES

The main effect of luminance was significant, $F(1,23)=49.586$, $p<.001$, $\eta^2_p=.684$. Participants performed better for dark (M:0.633, SD:0.059) than for bright dots (M:0.683, SD:0.073). The main effect of global letter was also significant, $F(1,23)=15.082$, $p=.001$, $\eta^2_p=.396$. Participants performed better for a global S (M:0.651, SD:0.064) than for a global H (M:0.665, SD:0.069). The main effect of local letter was significant as well, $F(1,23)=22.385$, $p<.001$, $\eta^2_p=.493$. Participants' performance was better for a local S (M0.651, SD:0.064) than for a local H (M0.665, SD:0.069). Finally, the interaction luminance x global letter was significant, $F(1,23)=4.384$, $p=.048$, $\eta^2_p=.159$. None of the other interactions were significant. To further examine the significant interaction, t-tests were conducted to compare the global letters H and S for both bright and dark dots separately.

The t-tests showed that participants only performed better for a global S (M:0.672, SD:0.070) than for a global H (M:0.695, SD:0.082) if the dots were bright, $t(23)=3.460$, $p=.002$.

4.2.3 Discussion

There were three main findings in this experiment. Participants performed better for dark dots than for bright dots. In addition, participants performed on both the global and local level better for the letter S, a finding which is more difficult to explain.

The main effect of luminance can be explained by the fact that the dots were presented against a white background (Buchner, & Baumgartner, 2007; Komban et al., 2011; Plainis, & Murray, 2000; Walkey et al., 2006). The letter identity effect might suggest that typicality of letters plays a role. The letter S as used in this experiment could be seen as a rather atypical representative of a letter, contrary to the letter H. However, previous research suggests that performance is generally better for typical targets (e.g. Maxfield et al., 2014; Rosch et al., 1976). At the same time, in chapter 3, it was suggested that performance was generally better when the dots were embedded horizontally (e.g. global H). This hypothesis was based on previous work that showed that performance is generally better on the horizontal than on the vertical (Collewijn, &

Taminga, 1984; Ingster-Moati et al., 2009; Schmidt et al., 1993; Yu et al., 2010). However, the results of this experiment suggest that embedment of the dots does not seem to be the only explanation for better performance for a specific letter because in this experiment, the position of the dots was always on the horizontal axis and was not confounded with letter identity.

It is possible that the better performance for global and local S occurred due to lateral masking. At least on the local level the special composition of the letters might have played a role, due to the fact that the H is bordered on the vertical whilst both I and S are bordered on the horizontal. However, no studies could be found that might support the explanation that performance is affected by special bordering. In addition, no interference effects occurred. This would be the most important finding for the question of this thesis, which aims to establish whether performance is facilitated if the global and local level match, even if participants carry out a task that is independent. In the series of experiments discussed in chapter 3, this interference effect occurred for bright I only. Therefore, to further test the impact of letter identity, a second experiment with the letters I and S was conducted. If performance is facilitated for matching conditions only when the dots are embedded vertically (thus when the global letter is an I), we should be able to replicate the matching effect. Similarly, we should not find the effect for the letter S, where the dots are embedded horizontally.

4.3 Experiment 2: I-S

The letters I and S were used in this experiment in order to find out whether task-irrelevant interference effects only occur for a global I if attention is directed to the local level (figure 22). The aim was also to find out whether task-irrelevant interference effects never occur for global letters where dots are embedded horizontally (S in this experiment).

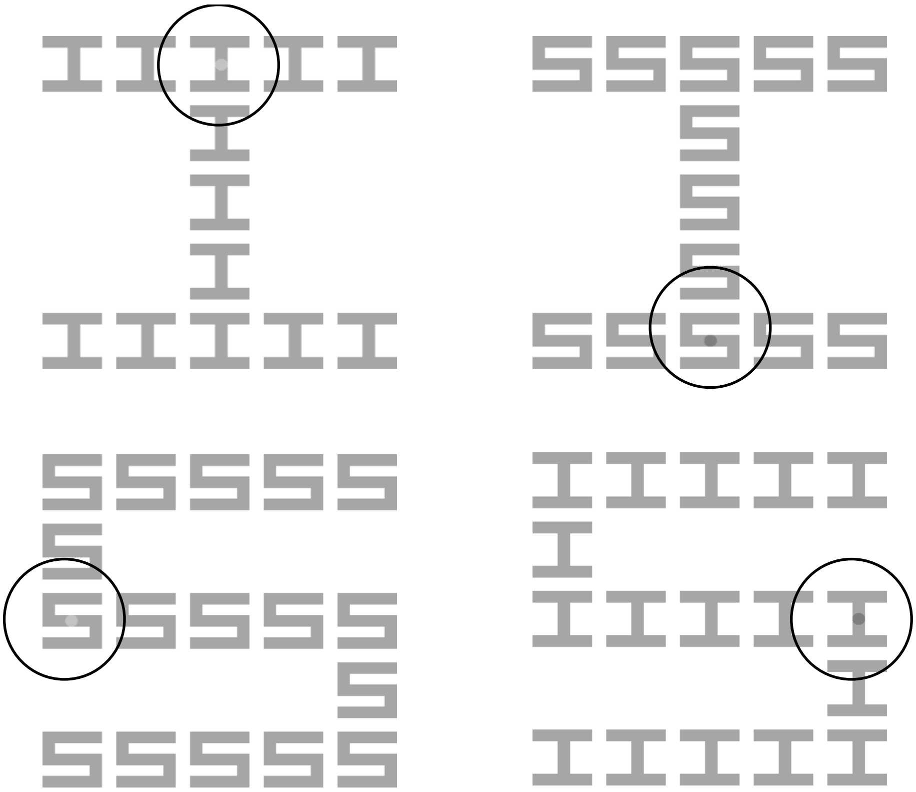

Figure 22: I-S experiment (local level)
Experiment 2: The top left image contains a bright dot embedded in a global I made up of local Is, which means that the global and local level of the letters are the same (matching condition). The top right image is a dark dot embedded in a global I made up of local Ss, which means that the global and local level of the letters are different (mismatching condition). The bottom left image contains a bright dot embedded in a global S made up of local Ss, which means that the global and local level of the letters are the same (matching condition). The bottom right image is a dark dot embedded in a global S made up of local Is, which means that the global and local level of the letters are different (mismatching condition).

4.3.1 Methods

Participants

23 students from the University of Birmingham took part in the experiment in exchange for course credits or monetary compensation. The inclusion criteria were normal or corrected-to-normal vision and normal colour vision. The mean age was 19.27 years (SD:0.79), 18 participants were female and 22 participants were right-handed.

Stimuli, Procedure, Design and Analysis

The experimental stimuli, procedure, design and analysis were the same as in experiment 1, apart from that this time, the global and local letters S and I were used. The dots were embedded in the middle left or right local letter (for the global S) or in the middle top or bottom local letter (for the global I). The exclusion criterion was again accuracy lower than 90% and according to this criterion, 2 participants had to be excluded from the analysis. Outlier removal was based on the same criteria as before and according to that, all trials with RTs higher than 1.19 s and lower than 0.34 s were excluded.

4.3.2 Results

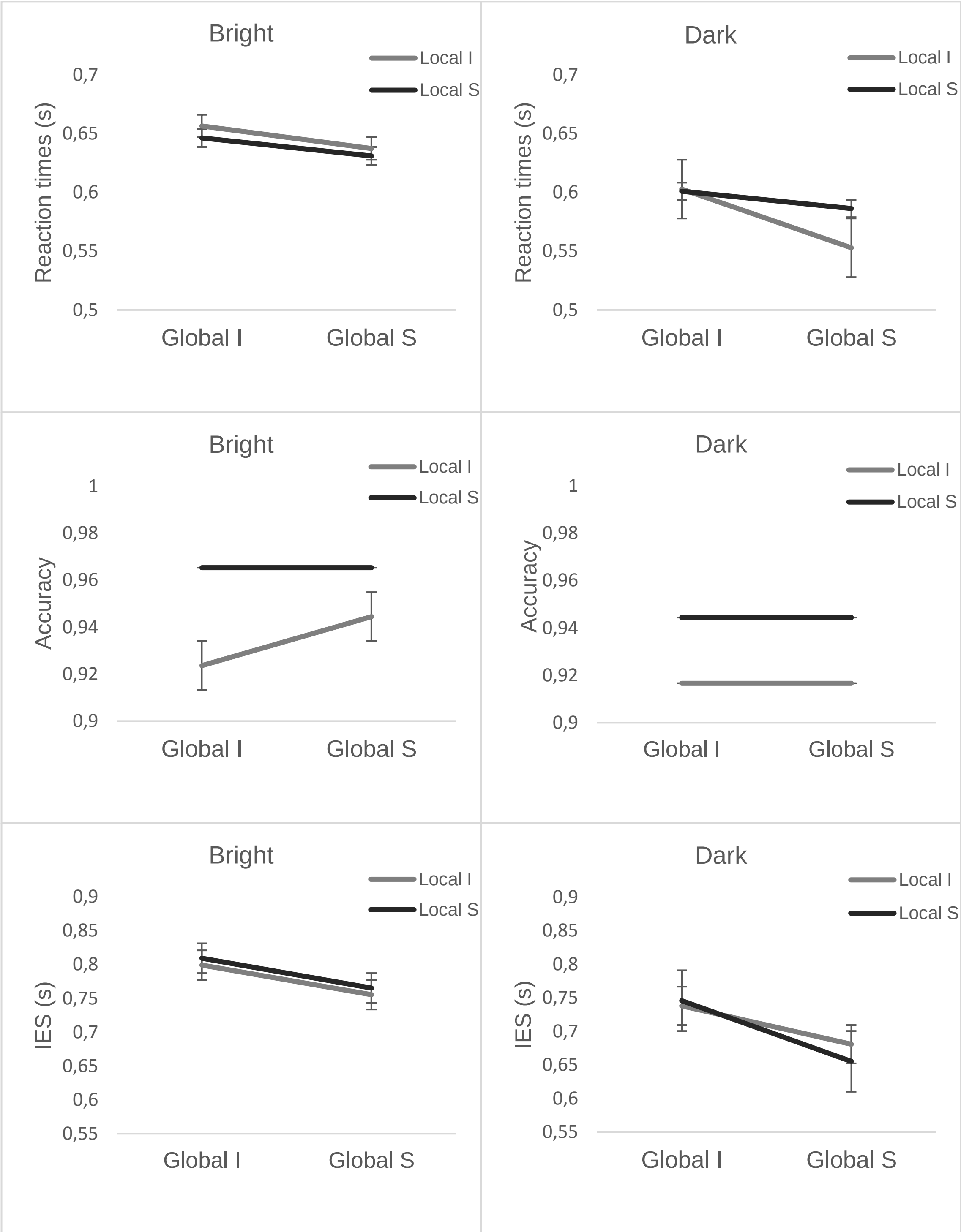

Figure 23: Results of the I-S experiment (local level)
Experiment 2: Participants responded faster to dark dots and to a global S. Participants were more accurate for bright dots, which means that there was a speed-accuracy trade-off. Participants performed better for dark dots and for a global S.

Reaction times

There was a significant main effect of luminance, $F(1,20)=70.868$, $p<.001$, $\eta^2_p=.780$. Participants responded faster when the dots were dark (M:0.676, SD:0.128) than when they were bright (M:0.621, SD:0.096). The main effect of global letter was also significant, $F(1,20)=51.324$, $p<.001$, $\eta^2_p=.720$. Participants responded faster when the global letter was an S (M:0.694, SD:0.105) than when it was an I (M:0.743, SD:0.119). The main effect of local letter was not significant, $F(1,20)=1.140$, $p=.298$, $\eta^2_p=.054$. The interaction luminance x local letter was significant, $F(1,20)=6.705$, $p=.018$, $\eta^2_p=.251$, and the interaction global letter x local letter was border significant, $F(1,20)=4.371$, $p=.050$, $\eta^2_p=.179$. None of the other interactions were significant. To further examine the significant interaction and the border significant interaction, simple effect analyses were conducted for both local I and S separately.

For local I, the main effect of luminance was significant, $F(1,20)=43.696$, $p<.001$, $\eta^2_p=.686$. Participants responded faster when the dots were dark (M:0.678, SD:0.096) than when they were bright (M:0.754, SD:0.128). The main effect of global letter was also significant, $F(1,20)=37.165$, $p<.001$, $\eta^2_p=.650$, with participants responding faster to a global S (M:0.696, SD:0.110) than to a global I (M:0.736, SD:0.115). The interaction was not significant.

For local S, the main effect of luminance was significant, $F(1,20)=87.960$, $p<.001$, $\eta^2_p=.815$. Participants responded faster when the dots were dark (M:0.674, SD:0.101) than when they were bright (M:0.769, SD:0.128). The main effect of global letter was also significant, $F(1,20)=39.947$, $p<.001$, $\eta^2_p=.666$, with participants responding faster for a global S (M:0.693, SD:0.105) than to a global I (M:0.750, SD:0.124). The interaction was not significant.

Accuracy

The main effect of luminance was significant, $F(1,20)=5.612$, $p=.028$, $\eta^2_p=.219$. Participants were more accurate for bright (M:0.975, SD:0.023) than for dark dots (M:0.963, SD:0.027). As they were also slower for bright dots, there was a speed-accuracy trade-off. The main effects of global letter, $F(1,20)=3.390$, $p=.080$, $\eta^2_p=.145$, and of local letter, $F(1,20)=3.485$, $p=.077$, $\eta^2_p=.148$, were not significant. None of the interactions were significant neither.

IES

The main effect of luminance was significant, $F(1,20)=63.352$, $p<.001$, $\eta^2_p=.760$. Participants performed better for dark (M:0.703, SD:0.115) than for bright dots (M:0.782, SD:0.133). The main effect of global letter was also significant, $F(1,20)=36.864$, $p<.001$, $\eta^2_p=.648$. Participants performed better for a global S (M:0.714, SD:0.115) than for a global I (M:0.773, SD:0.133). The main effect of local letter was not significant, $F(1,20)=.010$, $p=.923$, $\eta^2_p<.001$. None of the interactions were significant neither.

4.3.3 Discussion

Performance was again better for dark dots, because they were presented on a white background (Buchner, & Baumgartner, 2007; Komban et al., 2011; Plainis, & Murray, 2000; Walkey et al., 2006). In addition, like in the previous experiment, performance was better for the letter S, although in this experiment, this effect only occurred on the global level. It can be explained by the fact that the dots were embedded horizontally in a global S and vertically in a global I and it has been shown that performance is better on the horizontal than on the vertical (Collewijn, & Taminga, 1984; Ingster-Moati et al., 2009; Schmidt et al., 1993; Yu et al., 2010). Like in experiment 1, there was no interaction of the global level and the local level. This means that performance was not reliably impacted by matching or mismatching global and local letter identity. This result seems to contradict the hypothesis of this thesis, namely that a match of global and local letter identity facilitates performance even if participants do a task that is independent of letter identity. At the same time, it has to be noted that this time, we failed to replicate earlier findings in which the letter I facilitated performance when the global and local level matched either. This is in contrast to the experiments discussed in chapter 3. It suggests that the matching effect might not be as reliable for the letter I as previously assumed.

4.4 Between-experiments analysis HI and IS

4.4.1 Introduction

In order to find out whether performance along with interference effects are letter-identity dependent or not, a between-experiments analysis was conducted on the I-S experiment and the H-I experiment 3 from chapter 3. The reasoning for comparing those two experiments was the same luminance level of the dots and the same embedment of dots. The dots were embedded horizontally for the letter S as well as for H and vertically for I. Therefore, if there were any interactions with experiment, and if those interactions especially occurred for the global H/ global S, this would suggest that performance is letter-identity dependent.

4.4.2 Analysis

A mixed ANOVA was conducted on IES (in s) with the within-subjects factors global letter (H/S vs. I), local letter (H/S vs. I) and luminance (bright or dark) and the between-subjects factor experiment (HI vs. IS).

4.4.3 Results

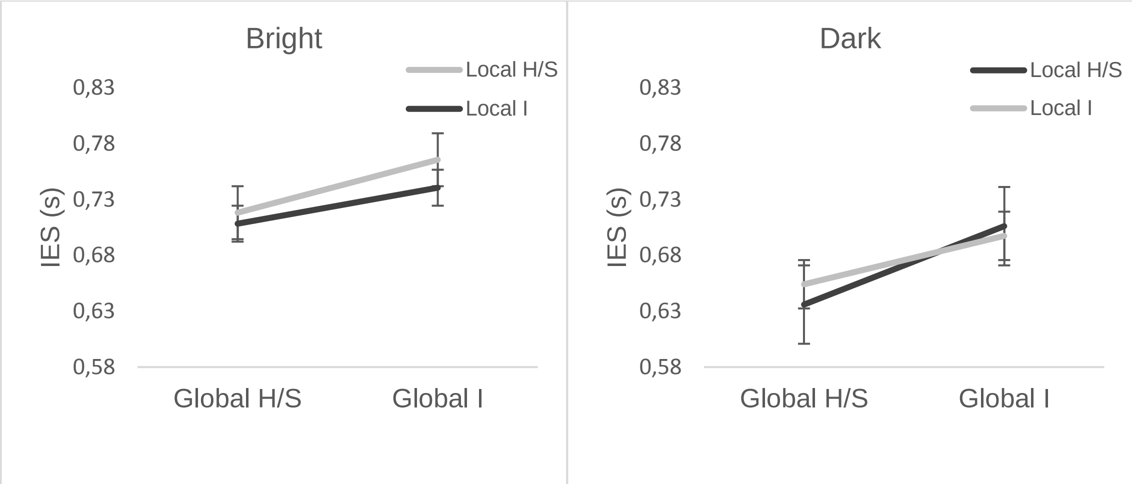

Figure 24: Between-experiments analysis of the IS and the HI experiment 3
Illustration of the interaction global letter (H/S vs. I) x local letter (H/S vs. I) x luminance. For a bright global I, participants performed better when the local letter was also an I. For a bright global H/S, participants performed also better when the local letter was an I, thus when the global and local letters were incongruent. In contrast, for a dark global H/S, participants performed better when the local letter was also an H/S, thus when the global and local letters were congruent.

IES

The main effect of global letter was significant, $F(1,39)=98.138$, $p<.001$, $\eta^2_p=.716$. Participants performed better for a global H/S (M:0.672, SD:0.102) than for a global I (M:0.725, SD:0.115). The main effect of local letter was significant as well, $F(1,39)=11.752$, $p=.001$, $\eta^2_p=.232$. Participants performed better for a local I (M:0.693, SD:0.101) than for a local H/S (M:0.705, SD:0.109). The main effect of luminance was also significant, $F(1,39)=78.175$, $p<.001$, $\eta^2_p=.667$. Participants performed better for dark (M:0.672, SD:0.101) than for bright dots (M:0.725, SD:0.115). Finally, the main effect of experiment was significant, $F(1,39)=7.392$, $p=.010$, $\eta^2_p=.159$. Participants performed better for the HI experiment (M:0.654, SD:0.154) than for the IS experiment (M:0.743, SD:0.147). The interactions local letter x experiment, $F(1,39)=10.689$, $p=.002$, $\eta^2_p=.215$, luminance x experiment, $F(1,39)=15.303$, $p<.001$, $\eta^2_p=.282$, global letter x luminance x experiment, $F(1,39)=4.888$, $p=.033$, $\eta^2_p=.111$, local letter x luminance, $F(1,39)=30.145$, $p<.001$, $\eta^2_p=.436$, local letter x luminance x experiment, $F(1,39)=5.433$, $p=.025$, $\eta^2_p=.122$, and global letter x local letter x luminance, $F(1,39)=6.187$, $p=.017$, $\eta^2_p=.137$, were significant. None of the other interactions were significant.

To examine the significant interaction global letter x local letter x luminance, simple effect analyses were first conducted on global H/S and I separately. For a global I, there was a significant main effect of local letter, $F(1,40)=11.782$, $p=.001$, $\eta^2_p=.228$, with participants performing better for a local I (M:0.718, SD:0.122) than for a local H/S (M:0.735, SD:0.122). The main effect of luminance was significant as well, $F(1,40)=34.660$, $p<.001$, $\eta^2_p=.464$. Participants performed better for dark (M:0.701, SD:0.122) than for bright dots (M:0.752, SD:0.128). The interaction local letter x luminance was also significant, $F(1,40)=4.634$, $p=.037$, $\eta^2_p=.104$. To further examine this interaction, t-tests were conducted on local H/S vs. local I for bright and dark dots separately. There was a significant effect for bright dots, $t(40)= -3.764$, $p=.001$, with participants performing better for a local I (M:0.739, SD:0.132) than for a local H/S (M:0.764, SD:0.126). For a global H/S, there was no main effect of local letter, $F(1,40)=1.785$, $p=.189$, $\eta^2_p=.043$. However, the main effect of luminance was significant, $F(1,40)=36.682$, $p<.001$, $\eta^2_p=.478$, with participants performing better for dark (M:0.644, SD:0.090) than for bright dots (M:0.702, SD:0.128). The interaction local letter x luminance was also significant, $F(1,40)=23.877$, $p<.001$, $\eta^2_p=.374$. To further examine this interaction, t-tests were conducted on local H/S vs. local I for bright and dark dots separately. There were significant effects for both luminance levels ($t(40)=3.954$, $p<.001$ for bright dots and $t(40)= -3.178$, $p=.003$ for dark dots). For bright dots, participants performed better for a local I (M:0.687, SD:0.131) than for a local H/S (M:0.717, SD:0.132). In contrast, for dark dots, they performed better for a local H/S (M:0.635, SD:0.088) than for a local I (M:0.653, SD:0.099).

To compare the interaction local letter x luminance x experiment, t-tests were conducted on local I vs. local H/S for bright and dark dots for both experiments separately. For the IS experiment, there was no significant effect of local letter, neither for bright nor for dark dots. For the HI experiment, there was a significant effect of local letter for bright dots, $t(19)= -7.596$, $p<.001$, with participants performing better for a local I (M:0.646, SD:0.084) than for a local H (M:0.692, SD:0.091).

To compare the interaction global letter x luminance x experiment, t-tests were conducted on global I vs. global H/S for bright and dark dots for both experiments separately. For both experiments, participants performed for both luminance levels better for a global H/S. For the IS experiment, the differences in performance for bright and dark dots were larger.

Table 1: Between-experiments analysis of the IS and HI experiment.
Results of the t-tests for the IS and HI experiment for bright and dark dots.

Experiment	**t-value**	**p-value**	**Mean H/S bright (SD)**	**Mean I bright (SD)**
IS	3.743	.001	0.760 (0.138)	0.804 (0.137)
HI	9.794	<.001	0.641 (0.086)	0.697 (0.089)
Experiment	**t-value**	**p-value**	**Mean H/S dark (SD)**	**Mean I dark (SD)**
IS	4.676	<.001	0.668 (0.097)	0.742 (0.140)
HI	6.911	<.001	0.620 (0.081)	0.658 (0.085)

4.4.4 Discussion

This between-experiments analysis revealed that better performance for letters with dots on the horizontal axis (global H/S) and better performance for dark dots seemed to be consistent. Better performance for a local I seemed to be less consistent, as this effect only occurred for bright dots, and this was only the case for the HI experiment.

The fact that participants performed better for a global H/S in both experiments suggests that embedment of dots affected performance. Performance is better when the dots are distributed horizontally compared to vertically. Importantly, the interaction global letter x local letter x luminance revealed that interference effects occurred for a bright I, independent of experiments (figure 24). However, the interaction local letter x luminance x experiment seems to contradict the generalisation of interference effects for a bright I, because only for the HI experiment, participants performed better for a local I if the dots were bright. This was not the case for the IS experiment. Interference effects also occurred for a dark H/S (figure 24). Here, it has to be noted that performance was better for dark dots than for bright dots and performance was also better for a global H/S than for a global I. This seems to suggest that on a local level, interference effects occur when performance is rather worse (bright I) or contrary, better than in other conditions (dark H/S). Hence, interference effects might depend on the time-course of responses and occur for responses that are rather fast or rather slow. However, the fact that interference effects occurred for both dark H/S and bright I might also show that local-level task-irrelevant interference effects are simply not consistent. This assumption can be strengthened by the explanation proposed in the general discussion of chapter 2 (global level experiments), where interference effects did not occur neither for the highest nor for the lowest luminance contrast. The highest luminance contrast condition should be the easiest condition and the lack of interference effects was explained by the attentional capture in this condition (e.g. Theeuwes, 2004; Yantis, 1993). However, it has to be mentioned that Mevorach et al. (2010) found that humans are able to ignore salient distractors. This finding would contradict the assumption of attentional capture and might explain why interference effects can also occur in conditions that might be relatively easy (shown by fast RTs for a dark H/S compared to other conditions). Conversely, the lowest luminance contrast condition should be the most difficult condition and the lack of interference effects was here explained with the cognitive resources needed in this condition (e.g. Lavie, 1995). However, interference effects occurred for a bright I on the local level. Considering that bright I showed long RTs and worse performance than other conditions, it should have also required more cognitive resources than other conditions. Therefore, interference effects for a bright I cannot be explained by cognitive resources that were required.

4.5 General discussion

This chapter aimed to find out whether interference effects in task-irrelevant Navon stimuli depend on the identity of the letter and associated position of the discrimination target. Rendering the Navon stimuli task-irrelevant was operationalised by asking the participants to respond to the luminance (bright or dark) of a dot that was embedded in one of the local letters (H or S and I or S, the global and local letters were congruent or incongruent) instead of responding to the letter itself. In chapter 3, where task-irrelevance was manipulated in the same way as in this chapter, the global and local letters H and I were used. It was shown that interference effects occurred, but this was only the case for one specific condition, namely for a bright I. Because in chapter 3 the position of the discrimination target was confounded with letter identity, the interference effect for the I might be explained as an artefact of target embedment. In this chapter, a new letter S was introduced to be compared with the letters H and I that were already used in chapter 3. The reasoning for choosing this letter was the same embedment of dots as for the letter H, which was used in chapter 3, namely on the horizontal. This was done in order to get further insight into the question whether embedment of dots might have played a role in the finding that interference effects only occurred for the letter I. If no interference effects occurred for the letter S, this might show that interference do not occur if dots are embedded horizontally. In addition, it was reasoned that that the typicality of the letters might have explained the difference between performance of the letters I and H. The H could be perceived as being much more typical and recognisable than the letter I. Similarly, the letter S of the present experiment might not be recognised as much, similar to the letter I. If interference effects occurred for the letter S, this might support the assumption that interference effects might occur for letters that are perceived as rather atypical.

In experiment 1, the letters H and S were used due to the same embedment of dots (figure 20), whereas in experiment 2, the letters I and S were used (figure 22) in order to find out whether the results are different if another letter than H is compared with I. In both experiments, performance was better for dark dots, a finding that already occurred in the experiments discussed in chapter 3. It can be explained with the fact that the dots embedded in the local letter were presented against a white background (Buchner, & Baumgartner, 2007; Komban et al., 2011; Plainis, & Murray, 2000; Walkey et al., 2006). In addition, performance was consistently better for the letter S. In experiment 1, this was the case on both the global and the local level, whilst in experiment 2, this result only occurred on the global level. For experiment 2, it can be best explained by the way the dots were embedded. For the letter S, the dots were presented on the horizontal, whilst for the letter I, they were embedded vertically and it has been shown that performance is generally better on the horizontal than on the vertical (Collewijn, & Taminga, 1984; Ingster-Moati et al., 2009; Schmidt et al., 1993; Yu et al., 2010). For experiment 1, it is more difficult to explain the better performance for the letter S. One possible explanation could be the typicality of the letters. Whereas the letter H can be seen as a rather typical representative of the alphabet, the letter S could be seen as more atypical, which might have caused better performance. However, it has to be noted that generally, typicality of letters rather facilitates performance instead of hindering it (e.g. Maxfield et al., 2014; Rosch et al., 1976). Another explanation could be lateral masking. This becomes clearer when looking at the composition of the letters: both I and S are bordered on the horizontal, whilst H is bordered on the vertical, which might explain the better performance for S than for H and also the better performance for a local I than for a local H in the series of experiments in the previous chapter. However, there is very little evidence in the literature supporting this potential explanation. Another important finding of experiment 2 was that interference effects did not occur for the letter I, in contrast to the experiments discussed in chapter 3. One possible explanation for the occurrence of interference effects for I that was proposed in the previous chapter was the embedment of dots. However, this interpretation is now challenged. A further assumption could be that typicality of letters leads to a facilitation in performance and an interference effect only occurs when the other letter is a typical representative of the alphabet, as it was the case for the letter H, but not for the letter S. However, according to this assumption, interference effects should have occurred in experiment 1, where the letter S was the atypical representative and the letter H a typical representative. It could be concluded that interference effects only occur if the dots are embedded vertically and the other letter is a typical representative. Finally, it has to be noted that in the series of experiments discussed in chapter 3, interference effects only occurred for the condition that seemed to be most difficult, i.e. in terms of the longest RT and performance, reflected in IES, namely a bright I. It is possible that in both experiments discussed in this chapter none of the conditions was so difficult that it facilitated performance when the global and local level matched.

In order to find out whether letter identity drives performance in the different experiments, a between-experiments was conducted on experiment 2 in this chapter and the HI experiment 2 from the previous chapter. The results of this analysis showed that some effects are consistent, such as better performance for a global H/S, that is to say when dots are embedded horizontally. Better performance for dark dots was also consistent. Interference effects were less consistent. They occurred for a bright I but also for a dark H/S (figure 24), suggesting that interference particularly occurs when performance is rather worse and responses are rather slow than in other conditions (bright I), or contrary, performance is rather good and responses trend to be faster than in other conditions (dark H/S). This shows that letter identity cannot account for all results. It also has to be mentioned that only in the HI experiment, interference effects occurred for a bright I.

In conclusion, the results of the present chapter seem to complicate the situation and it becomes evident that there are weaknesses to all explanations for the different performances for different letters in this chapter and in chapter 3. It is possible that task-irrelevant interference effects in Navon letters mainly occur when attention is directed to the global level, as it was the case in the experiments discussed in chapter 2, where interference effects were less letter-identity dependent. The occurrence of interference effects when performing another task might simply be less consistent when attention is directed to the local level. In addition, it is possible that splitting up the analysis into different global and local letters complicated the whole analysis, as the possible explanations focused on the specific letters, the luminance levels and the embedment of dots. The bright I effect might have been spurious. Therefore, in the next chapter an attempt was made to understand a broader perspective and a final analysis was conducted, where different letter identity was not taken into account and the results were analysed in terms of matching vs. mismatching conditions.

Chapter Five: ANALYSIS AVERAGED ACROSS LETTERS AND TIME-COURSE INVESTIGATION OF INTERFERENCE EFFECTS

5.1 Introduction

The previous chapters in this thesis investigated task-irrelevant interference effects in Navon stimuli on either the global (chapter 2) or the local level (chapters 3 and 4). Task-irrelevance was manipulated by asking participants to either respond to the luminance of the global letter embedded in a square in the global level condition or to the luminance of a dot embedded in one of the local letters in the local level condition. More specifically, participants were asked to indicate whether the letter or the dot was brighter or darker than its surrounding background. It was hypothesised that the task-irrelevant letters would be processed faster if they match than when they do not match. This was assumed based on Gestalt psychology principles. In Gestalt psychology, grouping of local stimuli to a global stimulus is particularly important (e.g. Rock, & Palmer, 1990). The grouping principles have been investigated in various studies and it has been shown that grouping of local stimuli and interference effects can occur without participants' attention and therefore are assumed to occur automatically (Kimchi et al., 2018; Montoro et al., 2014; Moore, & Egeth, 1997; Rashal et al., 2017). The literature about stimulus-stimulus-compatibility (SSC) and stimulus-response-compatibility (SRC) effects provided an additional rationale for the assumption that task-irrelevant stimuli would be processed, as it has been shown that irrelevant stimulus dimensions can slow down responses if they do not match with the relevant stimulus dimension (Kornblum, 1992; 1994). The classic Navon study (Navon, 1977; 1981) can be seen as one example of how irrelevant stimulus dimensions affect responses, as can be the Stroop task (Stroop, 1935). The Stroop task showed that task-irrelevant words are processed automatically. In the present chapter, it was assumed that task-irrelevant letters would also be processed automatically, similar to words.

In previous chapters, for both conditions (global and local level), and for both luminance levels (bright and dark), the different global and local letter identities were taken into account in the analysis. The rationale for doing the analysis based on different letter identities was that letter identity was task-irrelevant, so the question remained whether different letters would produce different interference effects. In addition, already the classic Navon experiment that we conducted (see chapter 2, experiment 1) revealed an interference effect on both the global and the local level for the letter H but only on the global level for the letter I. The rationale for doing the analysis based on the two different luminance levels was that previous research has shown that dark stimuli are processed faster and more accurately (Buchner, & Baumgartner, 2007; Komban et al., 2001). Whereas neither luminance nor letter identity seemed to have strong effects on interference in the global level condition (chapter 2), the occurrence of interference effects seemed to strongly depend on letter identity in the local level condition (chapter 3). Performance was better for a congruent bright I than for an incongruent bright I, whereas interference effects did not occur for the letter H at all (chapter 3). There was also a lack of interference effects when the letter S was used in chapter 4 and no interference effects occurred for the letter I either. Different explanations were proposed for the occurrence of interference effects in one specific condition on the local level (i.e. bright I). They mainly focused on the embedment of dots and the specific characteristics of the different letters. However, splitting up the analysis into different letters might have complicated the analysis. Therefore, the aim of the first part of this chapter is to simplify the analysis and establish whether independently of the identity of the letter, matching global and local letter benefit performance compared to mismatching global and local letters (5.2 and 5.3). Luminance was still taken into account in this new analysis, considering that it was the main experimental manipulation. Additionally, luminance had very strong effects especially in the local level conditions (chapters 3 and 4), where performance was generally better for dark dots. This overall general analysis has Experiment as a between-subject variable, interference (match vs. mismatch) and luminance (dark vs. bright response) as within-subject variables.

The next analysis (5.4) will compare both global and local level experiments together by averaging across letters and luminance responses and just taking interference, experiment and condition (global vs. local level) into account in the analysis. The rationale for this analysis is to find out whether there are clear differences between performance on the global and the local level and whether interference effects just occur in one condition but not in the other if all manipulations (different letter identities and luminance responses) are not taken into account. Additionally, the aim was to find out whether the luminance manipulation in the different experiments was successful and whether this differed on the global and the local level.

In the last part of this chapter (5.6. and 5.7), time-course of responses will be analysed by allocating the response times into ten different bins (from fastest to slowest responses). The rationale for this analysis is that in both the global level condition (chapter 2) and in the local level condition (chapter 3), interference effects seemed to have been modulated by the speed of responses. In chapter 2, interference effects seemed to occur for the conditions with the fastest responses. This seemed to be line with the cognitive control theory, which states that automatic processes are rather fast and controlled processes are rather slow and that efficient cognitive control can reduce interference effects (Bialystok et al., 2004; Coderre, & van Heuven, 2014; Jansma et al., 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984; Shiffrin, & Schneider, 1977; Stuss et al., 2011; White et al., 2018). Hence, interference effects should especially occur for fast responses. In contrast, in chapter 3, interference effects occurred for conditions with rather slow responses. These results can be explained when looking into experiments that investigated the time-course of interference effects (Bub et al., 2006; Cohen et al., 1990; Glaser, & Glaser, 1982, van Zoest et al., 2012). The results of those experiments revealed that interference effects increase when response times become slower, just like in our series of experiments in chapter 3. According to the bottleneck theory (e.g. Broadbent, 1958), interference effects are only expected to take place when the two processes overlap in time. Accordingly, whenever one process, either letter processing or luminance response, occurs much faster or must slower than the other process, there should be no interference effect. Consequently, the time-course of the interference effects is predicted to take on a reverse U-shape function (Pashler, & Johnston, 1988), such that no interference effects occur if responses are generally fast or slow. In our series of experiments in chapters 2 and 3, the luminance contrast between bright and dark letters or dots was manipulated (from highest to lowest luminance contrast), as this was predicted to manipulate speed of responses for each individual experiment, given that research showed that responses increase with decreasing luminance contrast (Plainis, & Murray, 2000; Walkey et al., 2006). However, while the luminance manipulation was intended to provide a substantial breadth in reaction time, it may not have created sufficient variability. Therefore, in order to look more closely at the time-course, the distribution in natural variation in speed of responses within each experiment was analysed in order to find support for the explanations that were suggested. Like in the previous chapters, both terminologies, matching and mismatching conditions, as well as congruent and incongruent conditions, were used.

5.2 Analysis on the global level

5.2.1 Methods

A mixed ANOVA with the within-subjects factors interference (match or no match) and luminance (bright or dark) and the between-subject factor experiment (1-4) was conducted on IES (in s)[3].

[3] In this chapter, for the global level experiments, experiments 1-4 correspond to experiments 2-5 in chapter 2. In order to provide a better comparison with the local level experiments, the experiments on the global level were labelled as experiments 1-4 in this chapter instead of being labelled as experiments 2-5.

5.2.2 Results

Figure 25: Global level experiments (chapter 2).
Participants performed better when the global and local level matched and when the letters were dark

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The main effect of interference was significant, $F(1,94)=5.537$, $p=.021$, $\eta^2_p=.056$. Participants performed better if the global and local letter matched (M:0.594, SD:0.089) than when they did not match (M:0.599, SD:0.089). The main effect of luminance was significant as well, $F(1,94)=6.372$, $p=.013$, $\eta^2_p=.063$, with participants performing better for dark (M:0.591, SD:0.089) than for bright letters (M:0.601, SD:0.089). The main effect of experiment was not significant, $F(3,94)=2.435$, $p=.070$, $\eta^2_p=.072$. None of the interactions were significant.

5.2.3 Discussion

This analysis supports the findings from chapter 2: interference effects generally occur, despite that the letters are task-irrelevant (figure 25). In addition, the lack of a significant interaction interference x luminance suggests that better performance for congruent conditions is independent of the luminance response (bright or dark). In other words, while there was a main effect of luminance (responses to dark letters were faster than to bright letters), this did not affect the interference effect. The hypothesis of the thesis seems to be confirmed: participants perform better for congruent conditions, even if they complete a task that is irrelevant to the letters.

The fact that participants performed better for dark letters can be explained with the fact that the letters in the square were presented against a white background, which made the dark letters more outstanding and supports the finding that was already discussed in the previous chapters, namely that high luminance contrasts lead to short RTs (e.g. Plainis, & Murray, 2000; Walkey et al., 2006) and that dark stimuli are generally processed faster and more accurately (Buchner, & Baumgartner, 2007; Komban et al., 2011). This main effect of luminance was not significant in chapter 2. This could be due to the fact that in this chapter, IES was analysed instead of RTs in order to compare the results of the global level condition with the local level condition. In the local level condition, a speed-accuracy trade-off occurred almost consistently, therefore IES was already calculated in the previous chapters (chapters 3 and 4). In order to find out whether a main effect of interference occurred on the local level if the analysis is averaged across the letters, the same analysis that had been done on the global level was conducted on the local level.

5.3 Analysis on the local level

5.3.1 Methods

A mixed ANOVA with the within-subjects factors interference (match or no match) and luminance (bright or dark) and the between-subject factor experiment (1-4) was conducted on IES (in s).

5.3.2 Results

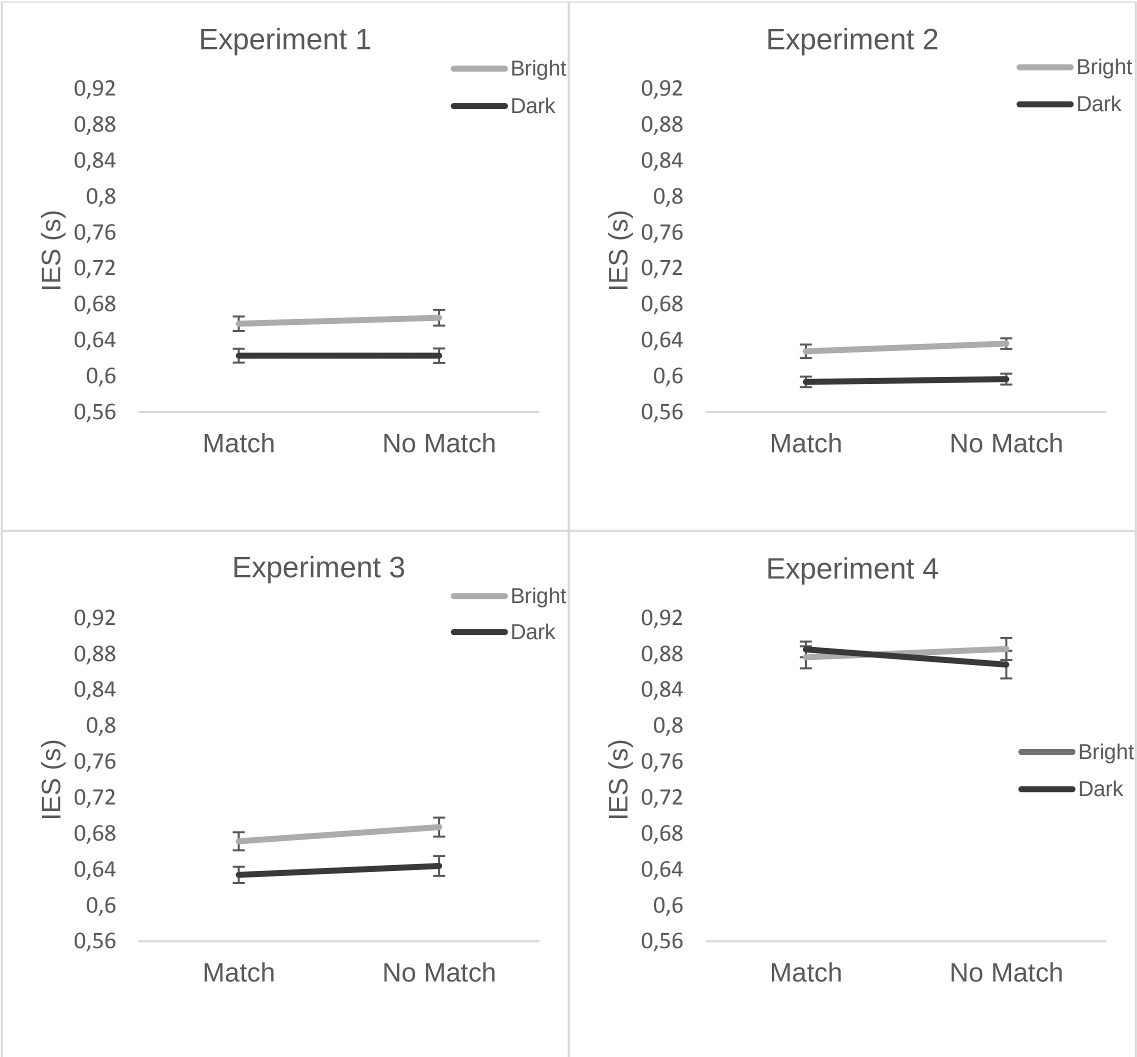

Figure 26: Local level experiments (chapter 3)
Participants performed better for matching conditions and for dark dots. They performed best for experiment 2, second-best for experiment 1, second-worst for experiment 3 and worst for experiment 4. In addition, for experiment 3, they performed better for matching conditions. For experiment 4, they performed better for mismatching conditions, but only when the dots were dark.

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The main effect of interference was significant, F(1,74)=6.662, p=.012, η^2_p=.083. Participants performed better when the letters matched (M:0.696, SD:0.088) than when they did not match (M:0.701, SD:0.079). The main effect of luminance was significant as well, F(1,74)=57.624, p<.001, η^2_p=.438. Participants performed better when the letters were dark (M:0.683, SD:0.079) than when they were bright (M:0.713, SD:0.088). The main effect of experiment was also significant, F(3,74)=39.211, p<.001, η^2_p=.614. Participants performed best for experiment 2 (second-highest luminance contrast, M:0.614, SD:0.167), second-best for experiment 1 (highest luminance contrast, M:0.642, SD:0.167), second-worst for experiment 3 (second-least luminance contrast, M:0.659, SD:0.167) and worst for experiment 4 (least luminance contrast, M:0.879, SD:0.177). The interactions interference x experiment, F(3,74)=3.725, p=.015, η^2_p=.131, luminance x experiment, F(3,74)=4.493, p=.006, η^2_p=.154, and interference x luminance, F(1,74)=7.610, p=.007, η^2_p=.093, were significant as well. The interaction interference x luminance x experiment was not significant. To further examine the significant interactions, simple effect analyses were completed for all experiments separately.

5.3.2.1 Simple effect analysis experiment 1

The main effect of luminance was significant, F(1,19)=31.329, p<.001, η^2_p=.622, with participants performing better for dark (M:0.623, SD:0.089) than for bright (M:0.662, SD:0.089) dots. The main effect of interference was not significant, F(1,19)=2.141, p=.160, η^2_p=.101. The interaction was not significant either.

5.3.2.2 Simple effect analysis experiment 2

The main effect of luminance was significant, F(1,19)=45.962, p<.001, η^2_p=.708. Participants performed better for dark (M:0.595, SD:0.063) than for bright (M:0.632, SD:0.072) dots. The main effect of interference, F(1,19)=4.112, p=.057, η^2_p=.178, and the interaction were not significant.

5.3.2.3 Simple effect analysis experiment 3

The main effect of interference was significant, $F(1,19)=19.601$, $p<.001$, $\eta^2_p=.508$. Participants performed better for matching (M:0.653, SD:0.085) than for mismatching (M:0.665, SD:0.085) conditions. The main effect of luminance was significant as well, $F(1,19)=22.374$, $p<.001$, $\eta^2_p=.541$. Participants performed better for dark (M:0.639, SD:0.080) than for bright (M:0.679, SD:0.089) dots. The interaction was not significant.

5.3.2.4 Simple effect analysis experiment 4

The main effects of interference, $F(1,17)=.469$, $p=.503$, $\eta^2_p=.027$, and of luminance, $F(1,17)=.171$, $p=.684$, $\eta^2_p=.010$, were not significant. However, the interaction interference x luminance was significant, $F(1,17)=5.863$, $p=.027$, $\eta^2_p=.256$. To examine this interaction, t-tests were conducted on matching vs. mismatching conditions for bright and dark dots separately. There was a significant interference effect for dark dots, $t(17)=2.125$, $p=.049$, with participants performing better if the letters did not match (M:0.858, SD:0.090) than when they matched (M:0.885, SD:0.097).

5.3.3 Discussion

Experiments 1-3 showed a significant main effect of luminance with a better performance for dark dots, which confirms previous findings that performance is better for dark stimuli (Buchner, & Baumgartner, 2007; Komban et al., 2011), as the dots were presented against a white background. This luminance effect was not significant for experiment 4, which can be best explained by the fact that overall, luminance contrast was low in this experiment, which rendered discrimination generally difficult. In addition, participants generally performed better for conditions with a higher luminance contrast. Although this effect was not consistent, it confirms previous findings (Plainis, & Murray, 2000; Walkey et al., 2006). Participants performed better for matching conditions in experiment 3 (figure 26), the condition with second-least luminance contrast. For experiment 3 in chapter 3, participants performed better for a congruent bright I. Therefore, results look similar in this chapter and in chapter 3. Although it could be concluded that speed of responses might influence interference effects, considering that responses were rather slow and performance was rather worse in this experiment than in the previous two experiments where luminance contrast was higher and where no interference effects occurred, results look different for experiment 4. Surprisingly, for this experiment, the condition with the least luminance contrast, participants performed better for mismatching conditions, but here it was only the case for dark dots (figure 26). The result for experiment 4 in this chapter looks similar to the results in chapter 3, where participants performed better for mismatching conditions for the letter H, independent of luminance response. Considering that this effect still occurred in this analysis but only for dark dots, it could be assumed that this effect was driven stronger by luminance response than by letter identity.

To just look at the effect of interference without the two different luminance responses but with taking the different experiments and conditions (global vs. local) into account, a last analysis was conducted, where bright and dark dots were averaged and only the factors interference, experiment and level (global vs. local) were taken into account. The aim was to establish whether there are clear differences between the global and the local level.

5.4 Analysis of the different conditions (global and local) collapsed over luminance

5.4.1 Methods

A mixed ANOVA with the within-subject factor interference (match vs. no match) and the between-subject factors experiment (1-4) and level (global and local) was conducted on IES (in s).

5.4.2 Results

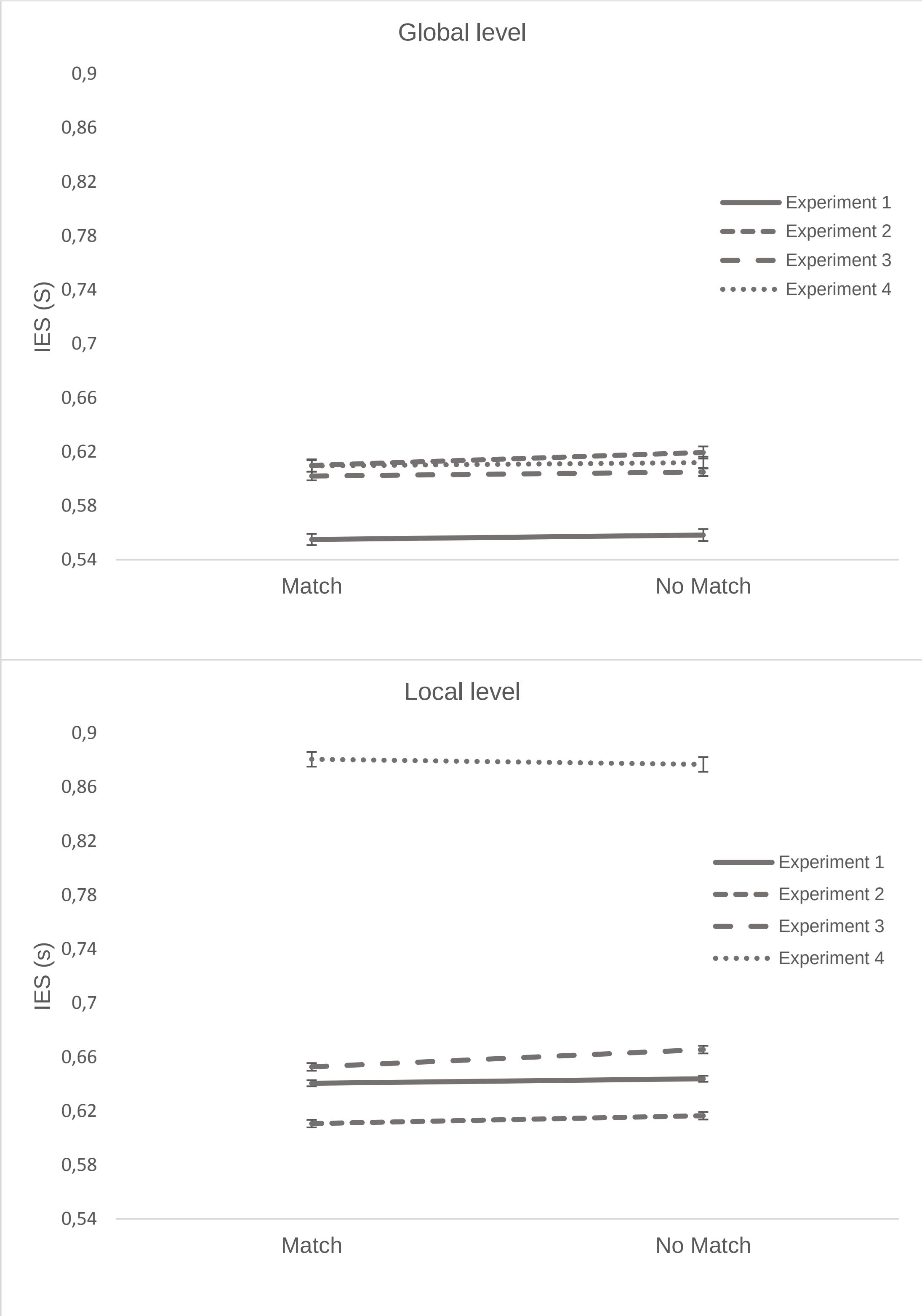

Figure 27: Analysis of interference, experiment and condition (global vs. local level)
Participants performed better for matching conditions and on the global level. Participants' performance also decreased for experiments with decreasing luminance contrast.

The main effect of interference was significant, $F(1,168)=11.513$, $p=.001$, $\eta^2_p=.064$. Participants performed better for matching (M:0.645, SD:0.093) than for non-matching conditions (M:0650, SD:0.093). The main effect of experiment was significant as well, $F(3,168)=25.235$, $p<.011$, $\eta^2_p=,311$. Participants performed best for experiment 1 (highest luminance contrast, M:0.599, SD:0.172), second-best for experiment 2 (second-highest luminance contrast, M:0.614, SD:0.172), second-worst for experiment 3 (second-least luminance contrast, M:0.631, SD:0.172) and worst for experiment 4 (least luminance contrast, M:0.745, SD:0.172). Finally, the main effect of condition was significant, $F(1,168)=61.751$, $p<.001$, $\eta^2_p=.269$. Participants performed better on the global level (M:0.596, SD:0.119) than on the local level (M:0.698, SD:0.133). None of the interactions were significant.

5.5 General discussion analysis averaged across letters

The aim of the first part of this chapter was to compare interference effects in task-irrelevant Navon stimuli for both global and local level tasks. The main finding for the global level task was that performance was facilitated in congruent conditions (figure 25). When the local and global letter matched, responses were faster than when they did not match. This better performance for congruent conditions was independent of the speed of responses and also independent of the luminance level. In other words, across experiments that vary widely in terms of overall reaction time, an interference effect is found that is seemingly not related to the overall speed of responding. Based on the results of chapter 2 it was suggested that the interference effect might depend on the overall speed of the responses, considering that interference effects seem to occur for conditions where responses were rather fast. The luminance manipulation of the different experiments was intended to explore the potential time-course of interference effects, especially the predicted reversed U-shaped function of the bottleneck theory (Pashler, & Johnston, 1988). While when looking at the average reaction times across experiments in the present analysis, time-course did not seem to affect the interference effect, it may still be the case that within each experiment, responses that are relatively faster are modulated differently by the irrelevant matching letters than responses that are triggered later in time (see also, van Zoest et al., 2012).

The bottleneck theory of attention (Broadbent, 1958) may in some ways explain the occurrence of interference effects on the global level. Accordingly, interference effects occurred because of concurrent competition between the luminance response and letter identification. However, considering that interference effects did not occur for one specific time interval, it would be difficult to establish a definitive bottleneck for a certain time-frame. In addition, participants were not instructed to respond to letter identity, so we cannot definitely say whether participants processed the letter identity or not. Furthermore, in experiments that test the bottleneck theory, the SOA interval is usually manipulated to test for potential interference effects. Interference usually occurs when the SOA interval between two different responses is around 0 (e.g. Appelbaum et al., 2012; Dyer, 1971; Glaser, & Glaser, 1982; Lu, & Proctor, 2001; Roelofs, 2010; Starrevald, & La Heij, 2017). However, this SOA interval was not manipulated in our series of experiments, because the only relevant response was luminance. The results showed that the interference effect was independent of the individual experiments and overall reaction times. Therefore, we did not find evidence for the predicted reversed U-shaped time-course prediction, which states that no interference effects should occur for high or low luminance contrast (Pashler, & Johnston, 1988).

On the local level, the results were less clear when the different letter identities were not taken into account anymore. The interaction interference x experiment revealed that no interference effects occurred for experiment 1 and 2, the conditions with higher luminance contrast and generally faster responses and better performance. This partly confirms the results from chapter 3, where interference effects only occurred for experiments 3 and 4, the conditions with the lower luminance contrast. However, for experiment 3, there was a main effect of interference in this chapter. In chapter 3, there was also an interference effect for experiment 3, but only for the letter I. While the observed interference effect for experiment 3 partly supports the time-course interpretation, showing that interference effects occur for rather slow responses, this interference effect could not be replicated in experiment 4, where responses were the slowest and performance was worst. In experiment 4, a reverse interference effect occurred for dark dots (figure 26).

It is worth noting that on both the global and the local level performance was better for dark stimuli. This can be explained by the fact that in both experiments, the stimuli were presented against a white background, which made the dark stimuli more outstanding, and by the fact that performance is generally better for dark stimuli (Buchner, & Baumgartner, 2007; Komban et al., 2001). The prediction that participants should generally show shorter responses for conditions with a higher luminance contrast could be partly confirmed, but only for the local level experiments, and also here it was not entirely consistent (Plainis, & Murray, 2006; Walkey et al., 2006).

In order to compare both the global and the local level series of experiments together, a last analysis was conducted with task (global or local level) as an additional between-subject factor, where responses were collapsed across luminance (bright and dark). These results revealed that independent of the task- whether participants' attention was directed to the global or the local level- they performed better for matching letters and they performed better for higher luminance contrast between letters/dots (figure 27). Additionally, participants performed better on the global level (figure 27), which is in line with previous studies about global precedence (e.g. Hughes et al., 1984; Navon, 1977; 1981; Paquet, & Merikle, 1988). This analysis therefore confirms all of our hypotheses.

In chapter 2 (global level), it was concluded that interference effects seem to occur for conditions with rather fast responses, whereas in chapter 3 (local level), it was found that interference effects seem to occur for the condition with rather slow responses. While the results in this chapter so far are mixed and do not clearly support a singular view in which interference depends on either fast or slow responses, it might still be the case that within each experiment, fast and slow responses are modulated differently (van Zoest et al., 2012). Therefore, to analyse the time–course, the distribution of participants' RTs were split into ten equal bins according to their speed of responses. Bin 1 corresponded to the fastest responses, whilst bin 10 corresponded to the slowest responses. If an interaction of interference and bin occurred, then the assumption could be made that the interference effect is related to the speed of responses. Like in the previous part of this chapter, the analysis was averaged across letters again because it was assumed that it was congruency or incongruency that led to the occurrence of interference effects, rather than different letter identity.

5.6 Time course analysis global level task

The motivation of this exploratory analysis was to find out whether within each experiment, fast and slow responses are modulated differently by the irrelevant letter identity (van Zoest et al., 2012). Time-course was analysed with the vincentizing procedure (Ratcliff, 1979). The RT distributions for each participant and each corresponding condition were divided into ten equally sized bins and the mean RTs were calculated for each decile. The aim was to test the assumptions that task-irrelevant interference effects seemed to occur for conditions with rather fast responses in the global level condition and for conditions with rather slow responses in the local level condition.

5.6.1 Analysis

A mixed ANOVA with the within-subjects factors interference (matching or mismatching conditions), luminance (bright or dark) and bin (1 – 10) and the between-subject factor experiment (1-4) was conducted on RTs in ms.[4]

5.6.2 Results

The main effect of interference was significant, $F(1,94)=6.633$, $p=.012$, $\eta^2_p=.066$. Participants responded faster to matching (M:592.051, SD:126.466) than to mismatching (M:596.908, SD:130.426) conditions. The main effect of bin was significant as well, $F(9,846)=212.846$, $p<.001$, $\eta^2_p=.994$. The main effects of luminance, $F(1,94)=2.175$, $p=.144$, $\eta^2_p=.023$, and experiment, $F(3,94)=.964$, $p=.413$, $\eta^2_p=.030$, were not significant. None of the interactions were significant either.

[4] In this analysis, outlier removal was based on 3 SDs above or below the mean RT for each individual participant, instead of 2 SDs above or below the overall mean RT. The reasoning for introducing the new outlier removal procedure was that in the old procedure, many trials of particularly fast or slow participants were excluded, whilst this new procedure enabled to include overall more trials and rather focused on variance in individual participants instead of variance amongst all participants. Only participants with an accuracy higher than 90% were included in this analysis.

5.7 Local level task

5.7.1 Analysis

The analysis and outlier removal procedure were the same as for the global level task in paragraph 5.6.1. All participants with an accuracy higher than 95% were included in this analysis.

5.7.2 Results

The main effect of interference was significant, $F(1,74)=8.363$, $p=.005$, $\eta^2_p=.102$. Participants responded faster to matching (M:698.073, SD:112.278) than to mismatching (M:705.856, SD:11.183) conditions. The main effect of luminance was significant as well, $F(1,74)=50.525$, $p<.001$, $\eta^2_p=.406$, with participants responding faster to dark (M:688.327, SD:112.737) than to bright (M:715.602, SD:112.737) dots. The main effect of bin was also significant, $F(9,666)=476.430$, $p<.001$, $\eta^2_p=.865$. Finally, the main effect of experiment was significant, $F(3,74)=25.548$, $p<.001$, $\eta^2_p=.508$. Participants responded fastest for experiment 2 (M:609.422, SD:219.937), second-fastest for experiment 1 (M:642.778, SD:219.937), second-slowest for experiment 3 (M:659.921, SD:219.937) and slowest for experiment 4 (M:895.738, SD:231.833). The interactions luminance x experiment, $F(3,74)=15.820$, $p<.001$, $\eta^2_p=.391$, bin x experiment, $F(27,74)=11.380$, $p<.001$, $\eta^2_p=.316$, interference x bin, $F(9,666)=7.826$, $p<.001$, $\eta^2_p=.096$, interference x luminance x experiment, $F(3,74)=5.399$, $p=.002$, $\eta^2_p=.180$, luminance x bin x experiment, $F(27,666)=12.507$, $p<.001$, $\eta^2_p=.336$, and interference x luminance x bin, F9,666)=2.243, $p=.018$, $\eta^2_p=.029$, were also significant. None of the other interactions were significant. To further examine the significant interactions, simple effect analyses were conducted on all four experiments separately.

5.7.2.1 Simple effect analysis experiment 1

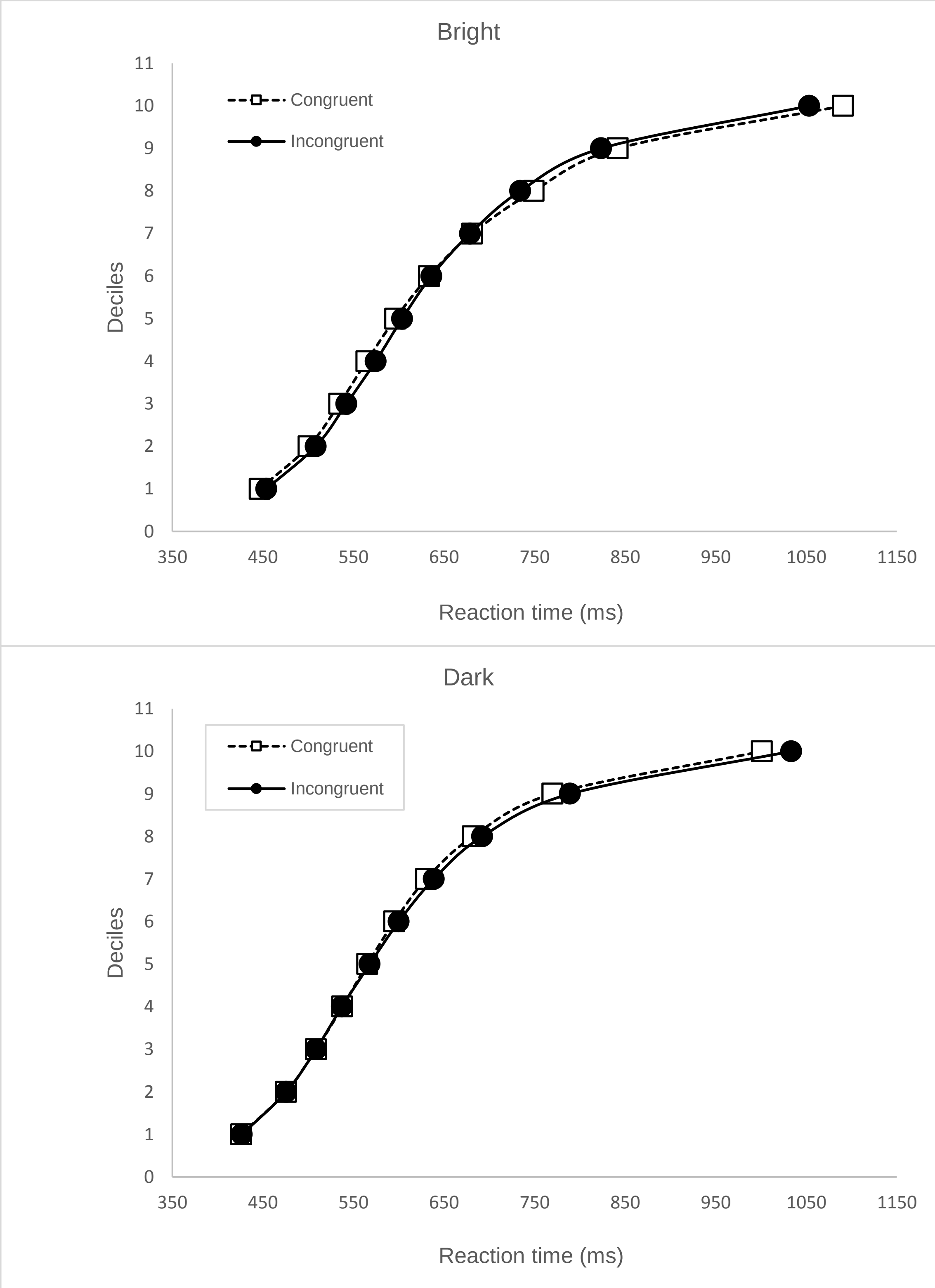

Figure 28: Time course of local level experiment 1 (chapter 3).
Participants responded faster to dark than to bright dots. For bright dots, participants also responded faster to congruent than to incongruent conditions, but only for bins 1-5.

The main effect of luminance was significant, $F(1,19)=40.008$, $p<.001$, $\eta^2_p=.678$. Participants responded faster to dark (M:623.151, SD:127.675) than to bright (M:662.406, SD:131.060) dots. The main effect of interference was not significant, $F(1,19)=.335$, $p=.569$, $\eta^2_p=.017$. The interaction interference x luminance x bin was significant, $F(9,171)=2.632$, $p=.007$, $\eta^2_p=.122$. None of the other interactions were significant. To further examine the significant interaction, simple effect analyses were conducted on both bright and dark dots separately.

For bright dots, the main effect of interference was not significant, $F(1,19)=.237$, $p=.632$, $\eta^2_p=.012$. However, the interaction interference x bin was significant, $F(9,171)=2.070$, $p=.035$, $\eta^2_p=.098$. To further examine this interaction, t-tests were conducted on matching vs. mismatching conditions for bins 1 – 10 separately. In order to account for problems with multiple statistical comparisons, α was adjusted by dividing 0.05 through 10. This led to the shift of significance from $p<.05$ to $p<.005$. The t-test was significant for bin 3, $t(-3.333)=.006$, with participants responding faster to matching (M:534.448, SD:72.621) than to mismatching (M:542.341, SD:70.159) conditions.

For dark dots, there was only a significant main effect of bin, $F(9,171)=52.646$, $p<.001$, $\eta^2_p=.735$. The main effects of interference, $F(1,19)=1.615$, $p=.219$, $\eta^2_p=.078$, and the interaction were not significant.

5.7.2.2 Simple effect analysis experiment 2

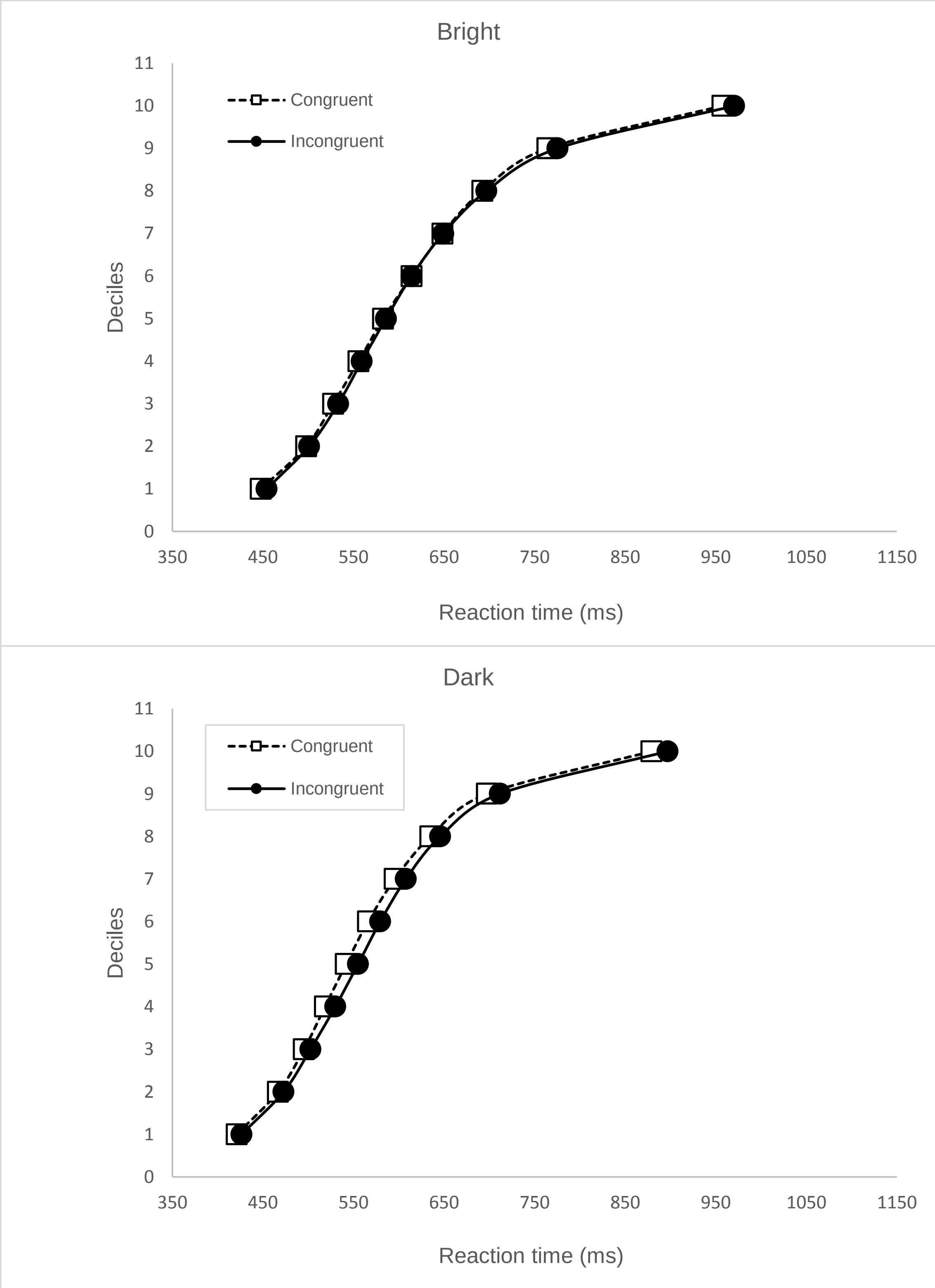

Figure 29: Time course of local level experiment 2 (chapter 3).
Participants responded faster to congruent than to incongruent conditions and they responded faster to dark than to bright dots.

Analysis averaged across letters and time-course investigation of interference effects

The main effect of interference was significant, $F(1,19)=9.872$, $p=.005$, $\eta^2_p=.342$. Participants responded faster to matching (M:605.365, SD:81.151) than to mismatching (M:613.478, SD:84.586) conditions. The main effect of luminance was also significant, $F(1,19)=47.157$, $p<.001$, $\eta^2_p=.713$. Participants responded faster to dark (M:587.357, SD:79.676) than to bright (M:631.486, SD:87.971) dots. The only significant interaction was luminance x bin, $F(9,171)=6.775$, $p<.001$, $\eta^2_p=.262$. To further examine this interaction, t-tests were conducted on bright vs. dark dots for bins 1 -10 separately (with α adjusted to 0.005). There were significant effects for all bins, with participants always responding faster to dark than to bright dots, but there were differences in the strength of this effect between the bins.

5.7.2.3 Simple effect analysis experiment 3

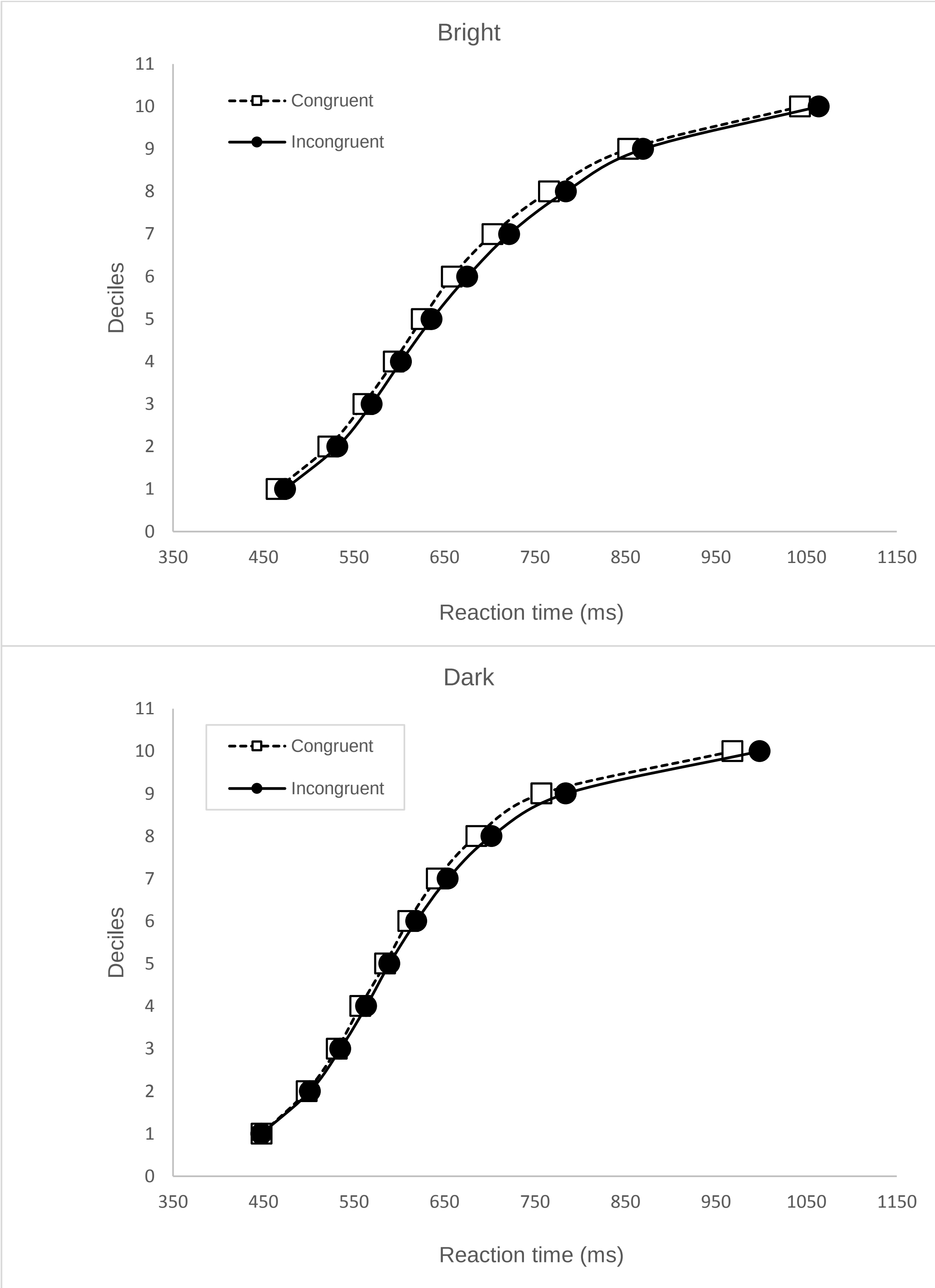

Figure 30: Time course of local level experiment 3 (chapter 3)
For bins 2-10, participants responded faster to congruent than to incongruent conditions and they responded faster to dark than to bright dots

The main effect of interference was significant, $F(1,19)=18.171$, $p<.001$, $\eta^2_p=.489$, with participants responding faster to matching (M:653.678, SD:108.579) than to nonmatching (M:666.164, SD:114.429) conditions. The main effect of luminance was also significant, $F(1,19)=27.980$, $p<.001$, $\eta^2_p=.596$. Participants responded faster to dark (M:633.862, SD:104.697) than to bright (M:121.682) dots. The interactions interference x bin, $F(9,171)=107.402$, $p<.001$, $\eta^2_p=.850$, and luminance x bin, $F(9,171)=3.986$, $p<.001$, $\eta^2_p=.173$, were also significant. None of the other interactions were significant. To further examine the interaction interference x bin, t-tests were conducted on matching vs. nonmatching conditions for bins 1 – 10 separately. They were significant for bins 4-9, all $p<.005$, with participants always responding faster to matching than to mismatching conditions. To further examine the interaction luminance x bin, t-tests were conducted on bright vs. dark dots for bins 1 – 10 separately. There were significant effects for all bins ($p<.005$), with participants always responding faster to dark than to bright dots, but there were differences the strength of this effect between the individual bins.

Table 2: Simple effect analysis bins experiment 3 (local level)
T-tests for matching vs. mismatching conditions for bin 4-9 for experiment 3 in the local level condition.

Bin	**t-value**	**p-value**	**Mean match (SD)**	**Mean mismatch (SD)**
4	-3.266	.004	572.421 (76.590)	579.352 (79.066)
5	-3.753	.001	600.495 (84.126)	609.477 (86.916)
6	-3.352	.003	632.191 (94.897)	643.306 (99.334)
7	-4.295	<.001	670.487 (106.092)	685.609 (114.931)
8	-4.414	<.001	723.804 (127.233)	743.677 (138.921)
9	-4.049	.001	808.424 (166.662)	830.655 (173.860)

5.7.2.4 Simple effect analysis experiment 4

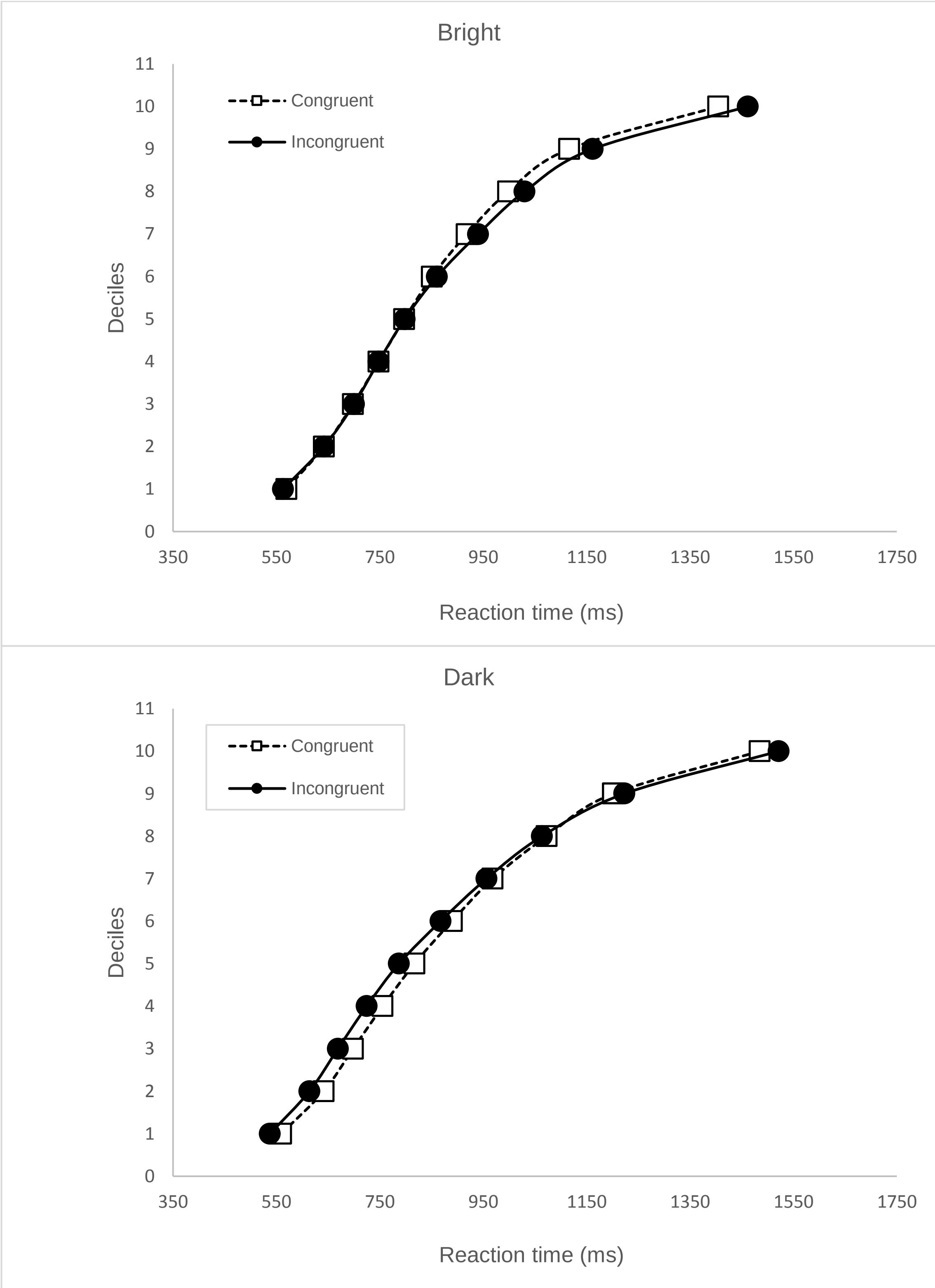

Figure 31: Time course of local level experiment 4 (chapter 3).
For bright dots, participants responded faster to congruent conditions. Whilst for bins 1-4, participants responded faster to incongruent conditions, they responded for bins 9 and 10 faster to congruent conditions[5].

The main effect of luminance was significant, $F(1,17)=4.515$, $p=.049$, $\eta^2_p=.210$. In contrast to the other experiments, participants responded this time faster to bright (M:882.536, SD:107.101) than to dark dots (M:902.703, SD:123.817). The interactions interference x luminance, $F(1,17)=9.127$, $p=.008$, $\eta^2_p=.349$, interference x bin, $F(9,153)=10.855$, $p<.001$, $\eta^2_p=.390$, and luminance x bin, $F(9,153)=22.279$, $p<.001$, $\eta^2_p=.567$, were significant as well. To further examine the significant interactions interference x luminance, t-tests were conducted on matching vs. mismatching conditions for bright vs. dark dots separately. There was a significant effect for bright dots, $t(17)= -2.354$, $p=.031$, with participants responding faster to matching (M:874.464, SD:106.884) than to mismatching conditions (M:890.609, SD:109.270).

To further examine the significant interaction interference x bin, t-tests were conducted for matching vs. mismatching conditions for bins 1 – 10 separately. A was again adjusted to 0.005. The t-test was significant for bin 1, $t(3.560)=.002$. Participants responded faster to mismatching (M:550.441, SD:42.582) than to matching conditions (M:564.567, SD:46.502).

5.8 Analysis accuracy based on new outlier removal

5.8.1 Introduction

Chapters 3 and 4 revealed that there was a speed-accuracy trade-off for the local level task. In order to establish whether with the new outlier removal procedure, this speed-accuracy trade-off still occurs for the local level task and whether it also occurs for the global level task, accuracy was analysed for both the global and the local level task. A mixed ANOVA with the within-subject factors interference (match or mismatch) and luminance (bright or dark) and the between-subject factor experiment (1-4) was conducted.

[5] Note that whilst the scale of the x-axis was 1150 ms for the previous 3 experiments, it is 1750 ms for this experiment, due to the long RTs in this experiment compared to the other experiments.

5.8.2 Results accuracy global level task

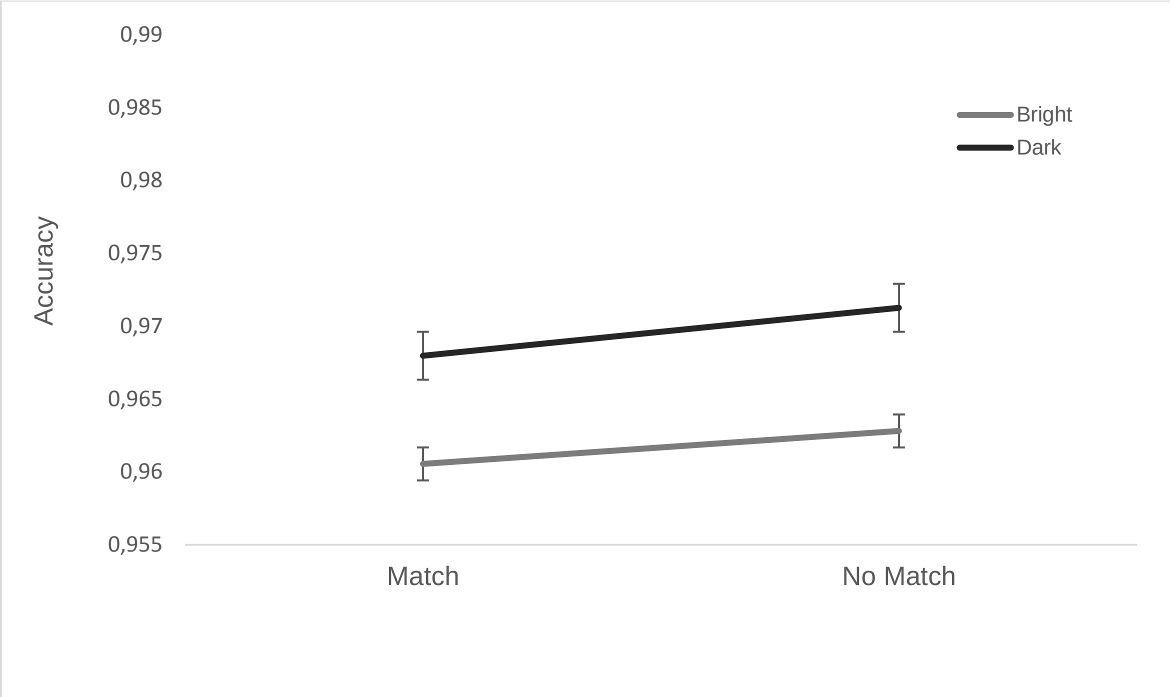

Figure 32: Accuracy of the global level experiments (chapter 2)
Participants were more accurate for dark than for bright letters. There was no speed-accuracy trade-off.

The main effect of luminance was significant, $F(1,94)=8.930$, $p=.004$, $\eta^2=.087$. Participants were more accurate for dark (M:0..970, SD:0.030) than for bright letters (M:0.962, SD:0.030). As there was no effect of luminance on RTs, there was no speed-accuracy trade-off. The main effects of interference, $F(1,94)=3.177$, $p=.078$, $\eta^2_p=.033$, and of experiment, $F(3,94)=.309$, $p=.819$, $\eta^2_p=.010$, were not significant. None of the interactions were significant. $F(1,17)=4.515$, $p=.049$, $\eta^2_p=.210$. The results support previous analyses of the global level task (chapter 2 and paragraph 5.2), which also revealed that participants were more accurate for dark letters. Therefore, it can be concluded that the new outlier removal procedure does not change these results.

5.8.3 Results accuracy local level task

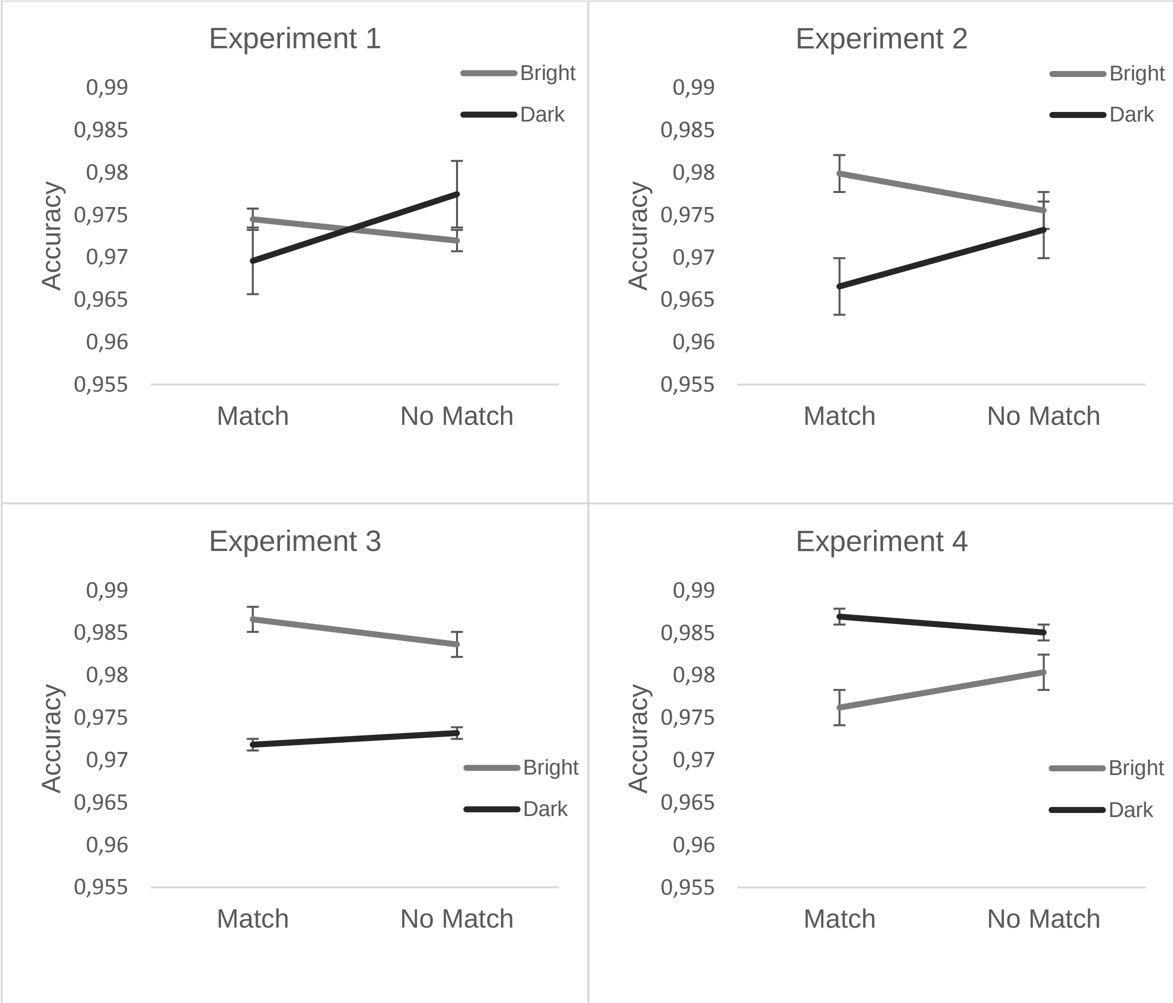

Figure 33: Accuracy of local level experiments (chapter 3)
For experiments 2 and 3, participants were more accurate for bright dots, whilst for experiment 4, they were more accurate for dark dots. Therefore, there was a speed-accuracy trade-off for those 3 experiments.

The main effect of luminance was significant, $F(1,74)=8.155$, $p=.049$, $\eta^2_p=.051$. Participants were more accurate for bright (M:0.979, SD:0.018) than for dark dots (M:0.975, SD:0.018). Therefore, there was a speed-accuracy trade-off, which already occurred in the analysis with the old outlier removal procedure (chapters 3 and 4). The main effects of interference, $F(1,74)=.399$, $p=.530$, $\eta^2_p=.005$, and experiment, $F(3,74)=1.770$, $p=.160$, $\eta^2=.067$, were not significant. The only significant interaction was luminance x experiment, $F(3,74)=8.155$, $p<.001$, $\eta^2_p=.248$. To further examine this interaction, t-tests were conducted on bright vs. dark dots for all 4 experiments separately. The t-tests were significant for experiment 2-4. For experiment 2 and 3, participants were more accurate for bright dots, whilst for experiment 4, they were more accurate for dark dots. Therefore, speed-accuracy trade-offs occurred in all 3 experiments and the IES was calculated.

Table 3: Accuracy new outlier removal (local level)
T-tests for accuracy for bright vs. dark dots for experiments 2-4 in the local level condition.

Experiment	t-value	p-value	Mean bright (SD)	Mean dark (SD)
2	2.555	.019	0.977 (0.016)	0.970 (0.017)
3	4.086	.001	0.985 (0.009)	0.973 (0.019)
4	-2.519	.022	0.978 (0.017)	0.986 (0.011)

5.9 Analysis IES local level task based on new outlier removal

5.9.1 Introduction

The analysis of accuracy for the local level task showed that also with the new outlier removal procedure, a speed-accuracy trade-off occurred for the factor luminance for experiments 2-4. Therefore, the IES was calculated and a mixed ANOVA with the within-subject factors interference (match or mismatch) and luminance (bright or dark) and the between-subject factor experiment (1-4) was conducted on IES (in s).

5.9.2 Results IES

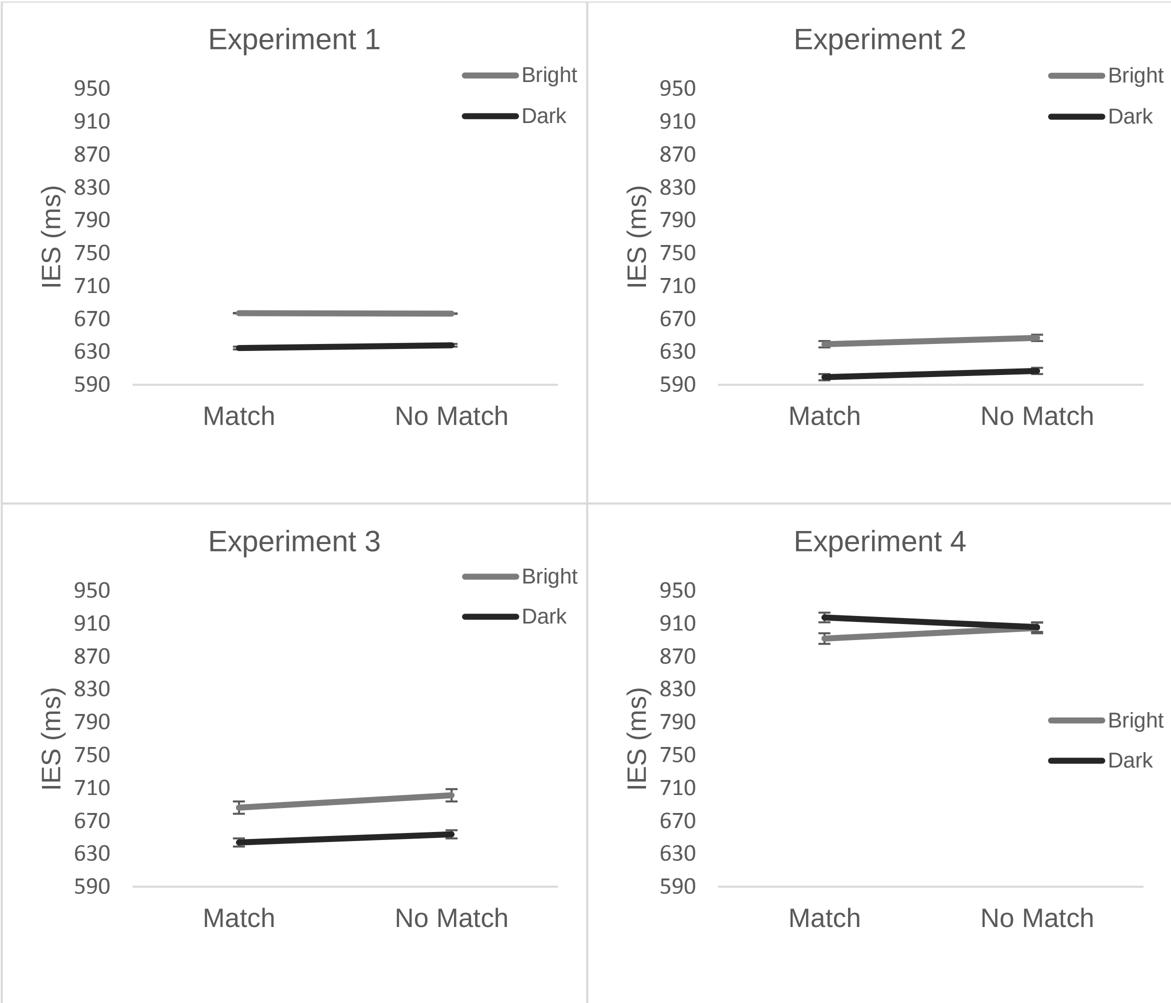

Figure 34: IES of local level experiments (chapter 3)
Participants performed better for matching conditions and for experiments 1-3, they also performed better for dark dots. Performance was best for experiment 2, second-best for experiment 1, second-worst for experiment 3 and worst for experiment 4.

The main effect of interference was significant, $F(1,74)=5.770$, $p=.019$, $\eta^2_p=.072$. Participants performed better for matching (M:711.165, SD:110.565) than for mismatching (M:716.693, SD:108.551) conditions. The main effect of luminance was significant as well, $F(1,74)=39.074$, $p<.001$, $\eta^2_p=.346$, with participants showing better performance for dark (M:699.909, SD:108.631) than for bright dots (M:727.949, SD:113.082). The main effect of experiment was also significant, $F(3,74)=25.875$, $p<.001$, $\eta^2_p=.512$. Participants performed best for experiment 2 (M:623.080, SD:215.212), second-best for experiment 1 (M:656.542, SD:215.212), second-worst for experiment 3 (M:671.214, SD:215.212) and worst for experiment 4 (M:904.882, SD:226.853). The only significant interaction was luminance x experiment, $F(3,74)=9.029$, $p<.001$, $\eta^2_p=.268$. To further examine this interaction, t-tests were conducted on bright vs. dark dots for all 4 experiments separately. The t-tests were significant for experiments 1-3, with participants always performing better for dark dots.

Table 4: IES new outlier removal (local level)
T-tests for IES for bright vs. dark dots for experiment 1-3 in the local level condition.

Experiment	t-value	p-value	Mean bright (SD)	Mean dark (SD)
1	5.679	<.001	676.765 (128.300)	636.319 (126.669)
2	5.929	<.001	643.145 (88.662)	603.015 (77.911)
3	4.400	<.001	693.674 (121.717)	648.753 (103.007)

5.10 General discussion

In this chapter, a new analysis was conducted where the different responses for both the global and the local level were allocated into ten different bins, from fastest to slowest responses. The analysis was done without taking the different letter identities into account to simplify the analysis and to increase power. The reasoning for allocating the response into different bins was that the previous analyses in the previous chapters revealed that interference effects seemed to depend on the speed of responses. On the global level, interference effects seemed to occur for conditions with rather fast responses (chapter 2). In contrast, on the local level, interference effects seemed to occur for the condition with rather slow responses and worst performance, namely for a bright I (chapter 3). Although the first part of this chapter revealed that when averaging across the different letters, then speed of responses did not seem to have as strong effects as previously assumed, it was suggested that within each experiment, task-irrelevant letter identity might modulate fast responses differently to responses that are triggered later in time (see, also, van Zoest et al., 2012). For this analysis, a new outlier removal procedure was introduced. In the previous chapters, the total mean of RTs over all participants was calculated and all trials higher or lower than 2 SDs from this mean were removed. However, this outlier removal procedure lead to the exclusion of many trials of particularly fast or slow participants. Therefore, in this analysis, the mean RTs of every individual participant were calculated and all trials higher or lower than 3SDs of those individual means were removed.

This new analysis revealed two important findings. First, even with the new outlier removal procedure many results from previous analyses (chapters 2-5) could be replicated, showing that both ways of removing outliers can be used. For the global level task, a main effect of interference occurred, which was independent of the speed of responses. On the local level, main effects of interference occurred for experiments 2 and 3 but were also less dependent on speed than previously assumed. All in all, this suggests that also on the local level, participants tend to take the global letter into account and that speed of responses has less strong effects as previously assumed. However, this effect of letter identity seems to be dependent on luminance contrast and does not occur neither for the highest nor for the lowest luminance contrast. Accuracy was also analysed on both the global and the local level to see whether a speed-accuracy trade-off still occurred. On the global level, the new outlier removal procedure did not change results. On the local level, a speed-accuracy trade-off also still occurred, so the IES was calculated again. For the IES, a main effect of interference now occurred, which was independent of experiments. This is in contrast to the findings of chapter 3 and the first analysis in this chapter, where there were no main effects of interference.

In contrast to previous assumptions that were made (chapters 2-4), faster responses to matching conditions were for both the global and the local level task independent of the speed of responses, which challenges all explanations which were given previously. The most plausible explanation for the finding that participants performed better for matching conditions in task-irrelevant Navon stimuli can be found when looking into SSC (Kornblum, 1992; 1994). The classic Navon task (Navon, 1977; 1981) and the Stroop task (Stroop, 1935) as well as the set-up of our experiments can be viewed under this paradigm: the irrelevant stimulus dimensions affects responses, as responses are generally faster if both the relevant and the irrelevant stimulus dimension match than when they do not match. This can be also transferred to our series of experiments, although we use the special case where we look into the match or mismatch of two irrelevant stimulus dimensions (global and local letter). Kornblum (1992) hypothesised that interference effects should still occur for those types of stimuli. It can be said that the results of both tasks used in this series of experiments, on the global and on the local level, provide important insight into task-irrelevant interference effects and they are an important addition to experiments that use the Navon paradigm. In addition, our series of experiments expand on the studies about Gestalt grouping that showed that Gestalt grouping and interference effects can occur without participants' attention, meaning that those effects occur automatically (Kimchi et al., 2018; Montoro et al., 2014; Moore, & Egeth, 1997; Rashal et al., 2017). The results of global level task also challenge some common findings about global precedence, such as that interference effects do not occur if attention is directed to the global level (Navon, 1977; 1981; see Hoffmann, 1980; Kimchi, 1992; Martin, 1979 for alternative results).

Chapter Six: CHOICE REACHING TASK (CRT) EXPERIMENTS

6.1 Introduction

The aim of this chapter is to find out how task-irrelevant local visual information is reflected in reaching trajectories. McCarthy and Song (2016) have looked into the research question of global and local visual processing being reflected in hand movements by using the CRT (Song, & Nakayama, 2008) and found that reach planning was initiated faster (reflected in initiation latency, IL) when a task-irrelevant illusionary global figure was present. The local shapes were Pac-men that formed a consistent or inconsistent global Kanizsa triangle. However, no effects on MD (the maximum deviation until the target is reached) were found. It can therefore be assumed that global processing is reflected in IL. Task-irrelevant interference effects have also been studied in hand movements by using the Stroop task and the Simon task (Buetti, & Kerzel, 2008; Bundt et al., 2018), generally finding that incongruent stimuli lead to more deviation in movement curvature (which is MD in the CRT). This leads to the hypothesis that task-irrelevant incongruent Navon stimuli should lead to more deviation in hand movements in a CRT.

In the RT experiments in chapters 3 and 4, it was investigated how task-irrelevant visual information is processed in Navon stimuli when participants' attention is locally directed. This was operationalised by asking participants to respond to the luminance of a dot embedded in a local letter. These local letters formed a global letter and the global and local level either matched or did not match. If the analysis was averaged across both letters used in the experiment and if outlier removal procedure changed (chapter 5), then interference effects generally occurred. As all previous experiments were pure RT tasks, the question remains whether the use of the CRT might give additional insight into the occurrence of task-irrelevant interference effects in Navon stimuli. Task-irrelevance was operationalised by asking participants to reach to the location of a dot embedded in one of the local letters. It was predicted that a mismatch of the global and local level would cause longer MD in a local level task CRT experiment, which was derived from the fact that interference effects occur when reaching trajectories are measured (Buetti, & Kerzel, 2008; Bundt et al., 2018). Additionally, the analyses of the RT experiments in this thesis mainly supported the prediction of task-irrelevant local-level processing along with interference effects (chapter 5). However, the null-hypothesis has to be proposed as an alternative assumption again. It is possible that in a CRT that tests task-irrelevant local processing, participants would simply not process the whole global letter and therefore, interference effects might not occur. It is important to be clear about the terminology again. As letter identity is task-irrelevant, the terms matching vs. mismatching conditions were used rather than congruent vs. incongruent conditions. However, especially when referring to the literature when discussing those effects, it is not always possible to make a clear distinction, therefore the words matching vs. mismatching and congruent vs. incongruent may be used interchangeably.

In experiment 1, the letters from chapter 4 (I and S) were used (figure 36) but instead of pressing a key on a computer keyboard as a response, participants were asked to reach to the location of the dot. To examine whether the same effects occur for matching and mismatching shapes, another experiment was conducted, where the shapes circles and squares were used (figure 38). Those shapes were chosen due to their relatively similar appearance and the possibility to embed dots at four different locations, similar to the locations of the letters I and S. Again, participants were asked to reach to a dot embedded in one of the local shapes. In line with the analysis from the previous chapter, just interference (match vs. mismatch) and luminance were taken into account in the analysis. If performance was worse in mismatching global and local conditions, which should be reflected in more deviation in MD, then this would support the hypothesis that in a local level reaching task both the global and the local level would be processed, even if task-irrelevant. We hypothesised no effects on IL because of the local level composition of this task.

6.2 Experiment 1: CRT letters

6.2.1 Methods

Participants

27 students from the University of Birmingham took part in the experiment in exchange for course credits or £6. The inclusion criteria were normal or corrected-to-

normal vision, normal colour vision and right handedness. The mean age was 20.26 years (SD:2.12) and 19 participants were female.

Stimuli

A big global letter H or I (5.7°) that was made out of smaller local letters, H or I (1.0°), was presented in the centre of the computer screen. The global and local level of the letters either matched or did not match. The letters were grey (RGB values: 149) and they were presented against a white background. The middle left or middle right vertical letter and the middle top or middle bottom horizontal letter contained a small dot (0.4°), which was either brighter (RGB values: 182) or darker (RGB values: 108) than its surrounding letter. The luminance level of the dots corresponded to the luminance level of the letters I and S in the RT experiment in chapter 4.

Procedure

Participants were seated 45 cm in front of a computer screen in a darkened room. Before every trial, a black fixation cross (0.9°) appeared in the centre of a black screen. After 2000 ms, a big global letter made out of smaller local letters was presented in the centre of the computer screen. Participants were asked to reach with their right index finger to the location of the dot and leave the finger on the screen until a new trial began after 1500 ms. IL reflected the time between the stimulus presentation and movement onset, with movement onset being defined as the first of five successive settings at which the index finger velocity surpassed 20 mm/s. MD was computed by taking the absolute deviation of the index finger trajectory from the straight line between the start and end of movement (see, figure 35 for an illustration). Participants' movement was recorded with video cameras.

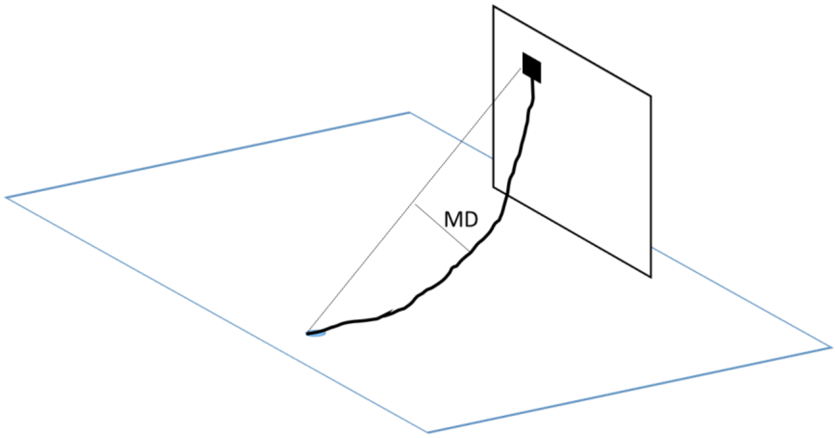

Figure 35: Illustration of MD measurement

Design

The experiment consisted of 4 blocks with 80 trials each. Before the start of the experiment, participants completed 10 practice trials. In each block, the number of both letters, matching and mismatching conditions, the dot luminance and the dot position was balanced.

Analysis

A three-way repeated measures ANOVA with the within-subject factors interference (match vs. mismatch) and luminance (bright or dark) was conducted on IL (in s) and MD (in cm). Outliers were removed based on the median absolute deviation (Ley et al., 2013) with a cut-off of 4 for each participant. Additionally, participants were removed if they produced more than 10% anticipatory trials (<100 ms) or had more than 20% outliers or their mean initiation latency was longer than 640 ms. 14 participants had to be excluded from the analysis according to these criteria.

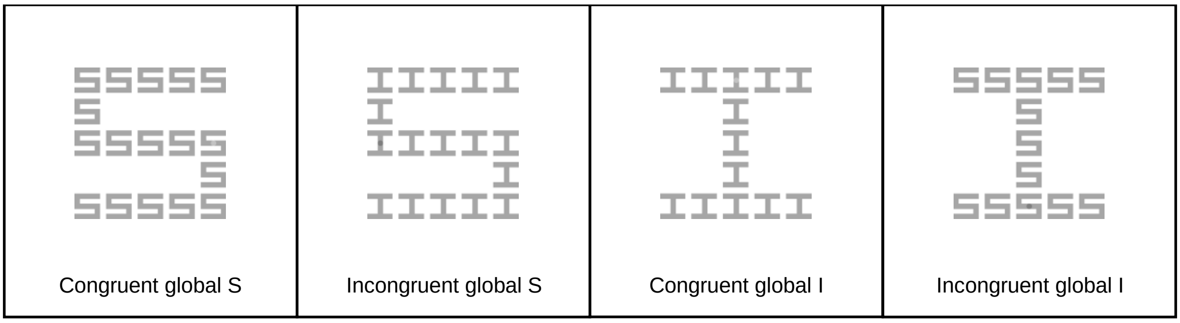

Figure 36: Stimuli of the CRT letter experiment

6.2.2 Results

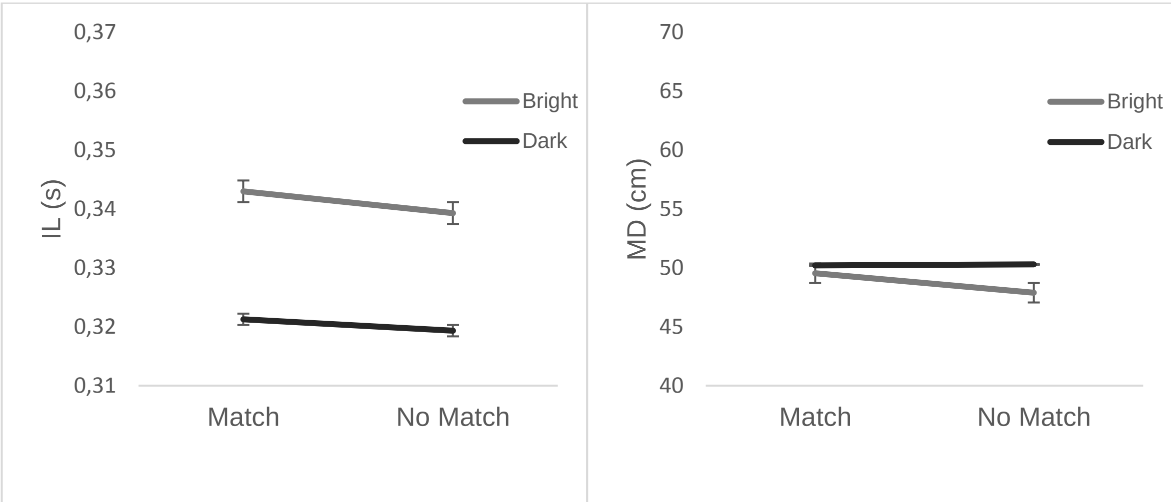

Figure 37: Results of the CRT letter experiment
Experiment 1: Participants needed longer to initiate their response when the dots were bright (reflected in IL). There were no significant effects on MD.

Initiation latency

The main effect of luminance was significant, F(1,12)=8.658, p=.012, η^2_p=.419. Participants needed longer to initiate their response when the dots were bright (M:0.322, SD:0.047) than when they were dark (M:0.329, SD:0.047). The main effect of interference, F(1,12)=1.431, p=.255, η^2_p=.107, and the interaction were not significant.

Maximum deviation

The main effects of luminance, $F(1,12)=.569$, $p=.465$, $\eta^2_p=.045$, and of interference, $F(1,12)=4.619$, $p=.053$, $\eta^2_p=.278$, were not significant. The interaction was not significant either.

6.2.3 Discussion

Against our prediction there was a main effect of luminance on IL. The fact that participants needed longer to start the movement when the dots were bright than when they were dark is in line with results from the previous chapters where RT was analysed (chapters 3, 4 and 5). It provides additional support for previous literature, stating that performance is generally better for a higher luminance contrast and when stimuli are dark (Buchner, & Baumgartner, 2007; Komban et al., 2011; Plainis, & Murray, 2000; Walkey et al., 2006). The finding that luminance only had effects on IL but not on MD suggests that this result is associated to RT, as supported by previous chapters (3, 4 and 5) but not to the actual execution of the movement.

There was no main effect of interference and no significant interaction for IL, which supports our hypothesis that task-irrelevant local-level interference effects should not be reflected in IL. We predicted that those interference effects should be reflected in MD, causing less deviation when the global and local level matched than when they did not match. However, the results of this experiment do not support this hypothesis. This leads to the assumption that although interference effects could be found when looking at RTs (chapter 5), the same effect cannot be replicated when using the CRT.

So far, in this thesis, possible effects of task-irrelevant global and local level processing were only examined by using letters. However, in previous studies, global and local level processing along with its associated interference effects were also studied by using shapes (e.g. Kimchi, & Merhav, 1991; Kimchi, & Palmer, 1982; 1985). Therefore, another experiment was set up, where the shapes circles and squares were used (figure 37), as both their global and local shapes are relatively similar (in contrast to for example squares and triangles). One important aim of conducting an experiment using shapes was to account for possible confounding of letter identity. The specific global and local identity of the letters used in this thesis might have influenced interference effects. For example, the dot locations of the global letters I and S used in the previous experiment influenced visual search. Therefore, despite using a local level task, the global letter identity inevitably affected participants' attention. In the next experiment, the same four possible dot locations were implemented for both global shapes, so that the global identity would not influence the local level search. Another important reason for using shapes instead of letters was to account for potential problems of letter familiarity, because both shapes, circles and squares, are familiar. The predictions remained the same as for the previous experiment: interference effects should occur, despite the shapes being task-irrelevant. Alternatively, the null hypothesis has to be proposed as well: task-irrelevance might not have any effects in the CRT.

6.3 Experiment 2: CRT with shapes

In order to find out whether task-irrelevant interference effects in CRT occur when task-irrelevant global and local shapes instead of letters are used, the shapes circles and squares were used (figure 38), as they enabled to implement the dots in the same locations as in the previous CRT experiment. Additionally, four possible dot locations were implemented in each individual shape, which were in line with the four possible dot locations in the letters I and S. The reasoning for choosing four possible dot locations for each individual shape was to account for any possible effects of dot position.

6.3.1 Methods

Participants

35 students from the University of Birmingham took part in the experiment in exchange for course credits or £6. The inclusion criteria were normal or corrected-to-normal vision, normal colour vision and right handedness. The mean age was 21.46 years (SD:4.34) and 31 participants were female.

Stimuli, Procedure, Design and Analysis

The stimuli, procedure, design and analysis were the same as in experiment 1, apart from that this time, shapes (circles and squares) instead of letters were used. The global stimuli had a visual angle of 13.9°, the local stimuli had a visual angle of 1.9°, and the dot had a visual angle of 1.0°. The outlier removal criteria were the same as for experiment 1. According to these criteria, 17 participants had to be removed from the analysis.

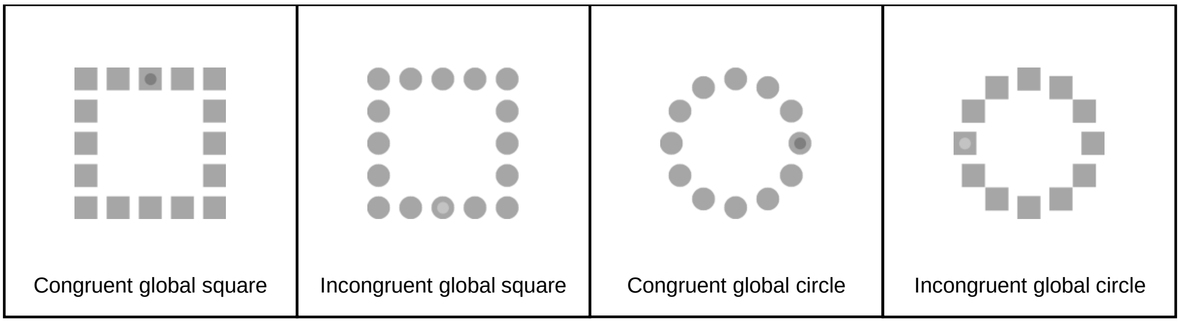

Figure 38: Stimuli of the CRT shape experiment

6.3.2 Results

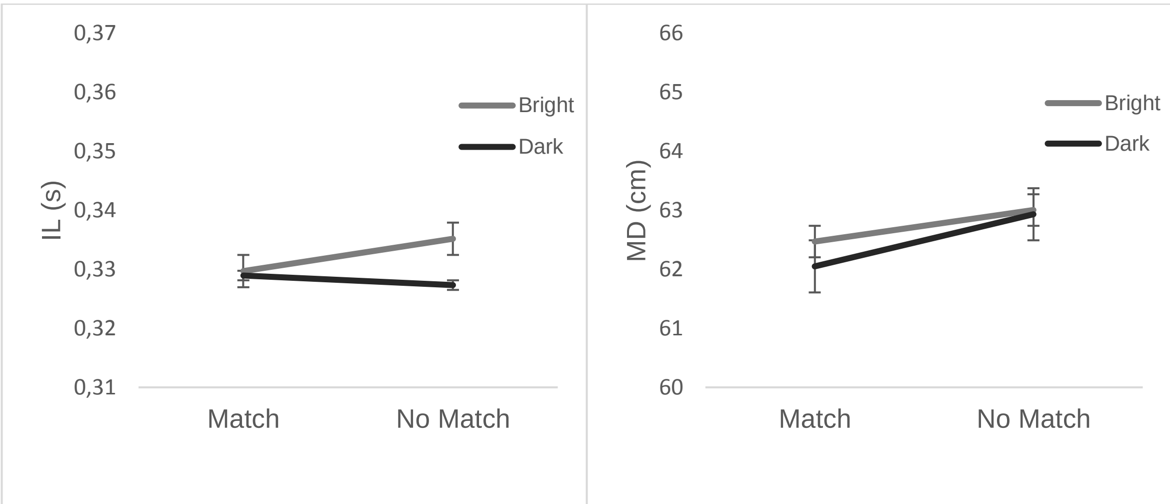

Figure 39: Results of the CRT shape experiment
Experiment 2: There were no significant effects neither on IL nor on MD.

Initiation latency

There were no significant main effects neither of interference, $F(1,17)=.612$, $p=.445$, $\eta^2_p=.035$, nor of luminance, $F(1,17)=2.892$, $p=.107$, $\eta^2_p=.146$. The interaction was not significant either.

Maximum deviation

There were no significant main effects neither of interference, $F(1,17)=1.151$, $p=.298$, $\eta^2_p=.063$, nor of luminance, $F(1,17)=.001$, $p=.975$, $\eta^2_p<.001$. The interaction was not significant either.

6.3.3 Discussion

Consistent with our hypothesis, no interference effects occurred for IL. It is important to note that, in contrast to experiment 1, luminance also did not have any effect on IL in this experiment. However, against our predictions, there were also no interference effects when MD was analysed either. This supports the results from experiment 1 but does not support the analysis of RTs from the previous chapter. Considering that interference effects did not occur neither for letters nor for shapes in this chapter, it has to be assumed that task-irrelevant interference effects might not occur on the local level in a CRT.

6.4 General discussion

This chapter aimed to establish how reaching trajectories are reflected in task-irrelevant Navon stimuli, as the usage of those stimuli enables to study task-irrelevant global and local processing. It was hypothesised that task-irrelevant local-level interference effects would occur. More specifically, this means that for task-irrelevant incongruent targets, a greater movement deviation was expected. Several theories and studies led to this assumption. First of all, the CRT (Song, & Nakayama, 2008) is a useful tool to study the time-course of cognitive processing by measuring reaching trajectories as it measures IL and MD. McCarthy and Song (2016) found that a task-irrelevant illusionary global figure facilitated reach planning (reflected in IL), whilst no effects on MD were found. Additionally, task-irrelevant interference effects in reaching trajectories were studied by using the Stroop task and the Simon task (Buetti, & Kerzel, 2008; Bundt et al., 2018), finding that reaching curvature is greater for incongruent trials. This led to the hypothesis that reaching curvature should be also greater in our task, where task-irrelevant interference effects were measured.

The RT experiments in the previous chapters showed that when doing a local level task, a task-irrelevant interference effect was generally found when the analysis was averaged across the different letters and they occurred even more consistently when the outlier removal procedure was changed (chapter 5). The aim of this chapter was to find out whether interference effects also occur if participants reach to the local location instead of responding to the luminance by pressing a key on a computer keyboard. Apart from the hypothesis that interference effects should occur in a CRT when task-irrelevant stimuli are used, the null hypothesis was proposed as well: no interference might occur, because participants might not process the letters when reaching to the location of the dot. In experiment 1, the letters I and S were used, whereas in experiment 2, the shapes circles and squares were used in order to find out whether shapes might produce different effects than letters.

Participants needed longer to initiate their response (reflected in IL) when the dots were bright in experiment 1. This supports previous findings from the RT experiments, where RTs were longer for bright dots (chapters 3, 4 and 5). It can be concluded that worse performance for bright dots is not only reflected in RTs but also in hand movements. This can be explained by the fact that the whole stimulus was presented against a white background, making the dark dots more outstanding and easier to detect.

In contrast to our predictions, a mismatch of the global and local level did not lead to more deviation, neither when letters nor when squares were used. It is possible that there was no interference effect on MD because a CRT might simply not be the best task to measure task-irrelevant interference effects on a local level. One possible future study could therefore combine global and local processing and the possible occurrence of interference effects in a CRT. If local processing was still not reflected at all neither in IL nor in MD, this would confirm our results and therefore confirm the null hypothesis. However, if local processing was reflected in MD and global processing was reflected in IL, this would confirm the hypothesis that we suggested at the beginning.

It is important to acknowledge the fact that in both experiments in this chapter, approximately half of the participants were excluded from the analysis. This can be mostly explained by technological problems and should therefore not be in concern in terms of the design of the experiments. Many participants did not leave their index finger for a sufficient amount of time on the computer screen. This led to problems in the recording of MD.

Chapter Seven: GENERAL DISCUSSION

7.1 Introduction

The present thesis investigated the occurrence of task-irrelevant automatic interference effects in a visual attention task using Navon letters (Navon, 1977; 1981). The usage of the Navon letters enabled to study task-irrelevant interference effects when attention is directed to either the global or to the local level. This is an important difference between the Navon task and other studies, such as the Stroop task (Stroop, 1935) or the Eriksen flanker task (Eriksen, & Eriksen, 1974), where the differentiation between global and local level is not possible.

To test whether Navon stimuli are processed automatically, the Navon letters were rendered task-irrelevant by asking participants to indicate whether the task-relevant luminance was brighter or darker than the background while at the same time still presenting the Navon stimuli. The manipulation of the luminance was independent of the letter identity. In chapter 2, the letters' luminance was manipulated, whilst in chapter 3, the luminance of a dot embedded in the letters was manipulated. In both chapters 2 and 3, the letters H and I were used. It was hypothesised that the Navon letters would be processed and influence performance, despite being task-irrelevant. Performance was predicted to be better if the global and local level matched than when they did not match. However, it is important to note that the predictions differed for the global and the local level tasks. For the global level task, it was predicted that both the global and the local letter would be processed, based on the standard global precedence effect (e.g. Navon, 1977; 1981). In contrast, for the local level task, two predictions were made. On the one hand, it could be assumed that even when doing a task on the local level, participants would still take the global letter into account (e.g. Grice et al., 1983; Heinze, & Münte, 1993; Hoffmann, 1980; Kimchi, 1992; Martin, 1979). On the other hand, it could be possible that when completing a local-level task, participants would not attend the whole global letter (Gasper, & Clore, 2002; Huntsinger, et al., 2010). In the analysis, the specific identity of the global and local letters was taken into account because letters were task-irrelevant, so the question remained whether performance would depend on letter identity. The two possible luminance responses (bright or dark) were also taken into account in the analysis, because it was predicted that performance should be better for dark letters/dots (e.g. Buchner, & Baumgartner, 2007; Komban et al., 2001).

There were two different hypotheses for the time-course of those predicted interference effects.

1) The cognitive control theory served as one hypothesis. It states that automatic processes are fast, whilst controlled processes are slower in time and that efficient cognitive control reduces interference effects (Bialystok et al., 2004; Coderre, & van Heuven, 2014; Jansma et al., 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984; Shiffrin, & Schneider, 1977; Stuss et al., 2011; White et al., 2018). This led us to the prediction that interference effects should occur for conditions where responses are rather fast. In contrast, when responses are slow, no interference effects were predicted, as cognitive control would have been established.
2) According to the bottleneck theory, which states that interference effects occur if two competing processes are happening simultaneously (Appelbaum et al., 2012; Broadbent, 1958; Dyer, 1971; Glaser, & Glaser, 1982; Lu, & Proctor, 2001; Roelofs, 2010; Starrevald, & La Heij, 2017), we predicted that interference would occur if there is a competition between luminance response and letter processing. It is important to note that we predicted a reverse U-shape function: no interference effects should occur for the conditions with the highest and the lowest luminance contrast (Pashler, & Johnston, 1988).

It was aimed to manipulate speed of responding by manipulating luminance contrast. This was done by implementing four different luminance contrasts (ranging from highest to lowest luminance contrast) for both the global and the local level task, but between experiments. It has been shown that RTs increase with decreasing luminance contrast (Plainis, & Murray, 2000; Walkey et al., 2006). Within experiments, it was aimed to manipulate speed of responding by manipulating the luminance response, i.e. bright or dark stimuli, based on the finding that performance is generally better for dark stimuli (e.g. Buchner, & Baumgartner, 2007; Komban et al., 2001).

Whilst in chapters 2 and 3, the letters H and I were used as experimental stimuli, in chapter 4, an additional letter S was introduced in order to investigate any possible effects of letter identity on interference. Chapters 2-4 were RT tasks; participants responded to the luminance by pressing a key on the computer keyboard. In those chapters, the time-course within experiments was investigated by looking at the mean RT of the whole sample. It was examined whether the relative response speed to targets of different luminance led to differences in the interference effects both within experiments and between experiments. In chapter 5, the analysis was averaged across the different letters. Additionally, time-course within experiments was analysed in more depth and by vincentizing (Vincent, 1912) individual participant distributions and looking separately at fast and slow responses. Additionally, in chapter 5 the global and local level conditions were compared directly. In chapter 6, task-irrelevant interference effects in Navon stimuli were investigated by using the choice reaching task (CRT, Song, & Nakayama, 2008; 2009), which enables to study the time-course components of reaching trajectories in hand movements as well as the time-course of cognitive processing. By using the CRT the IL can be measured. The CRT also enables to measure maximum deviation (MD, the curvature of the movement until the target is reached). We measured both components of reaching movement in our task. It was hypothesised that task-irrelevant local-level interference effects should be reflected in MD, with a greater curvature for incongruent stimuli.

7.2 Summary and interpretation of results

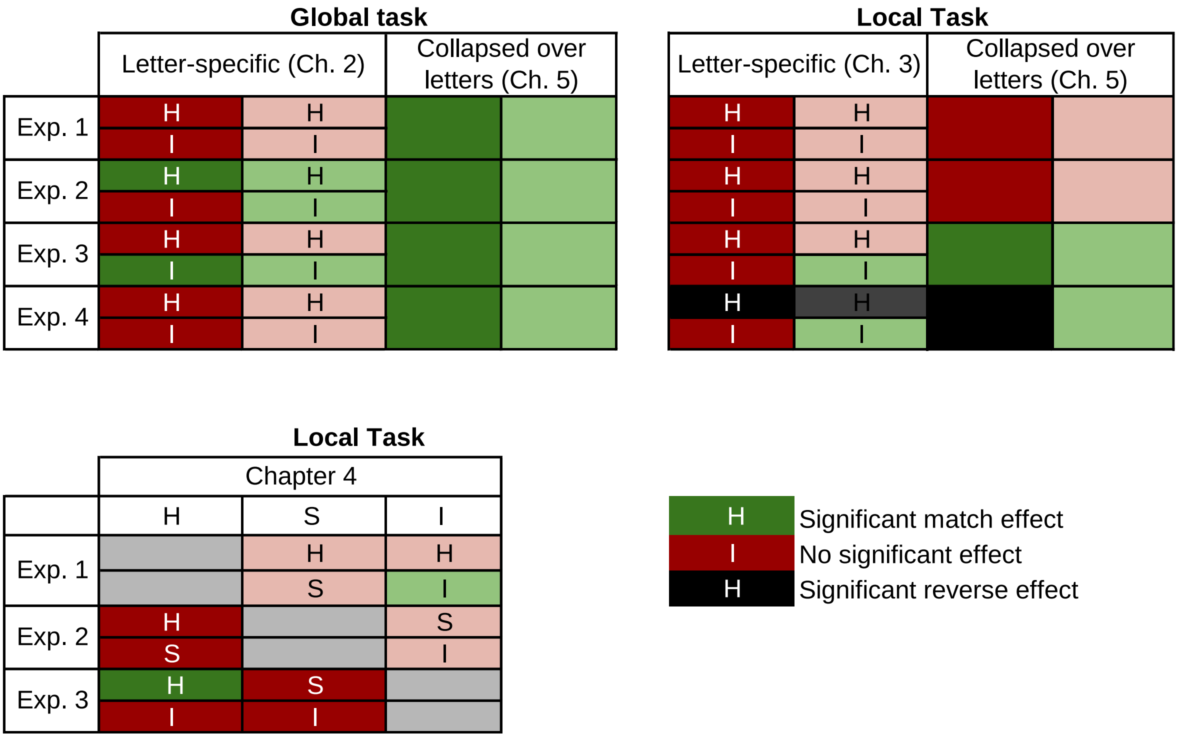

Figure 40: Illustration of the interference effects of chapter 2-5
Illustration of the match (interference) effect for the different letters, luminance responses and experiments in chapters 2-4. A dark coloured background represents dark letters/dots, whilst a bright coloured background represents bright letters/dots. The different letters written in the boxes represent the global letter that was formed. No letters written in the boxes represent the analysis collapsed over the different letters (chapter 5). A green background represents a significant matching effect, whilst a red background represents no significant matching effect. A black background represents a significant reverse matching effect. On the global level, (chapter 2), significant interference effects occurred for both letter identities, H and I, and for both luminance responses, bright and dark (experiments 2 and 3). No interference effects occurred neither for the highest nor for the lowest luminance contrast (experiments 1 and 4). On the local level (chapter 3), significant interference effects only occurred for a bright I and only for the conditions with a lower luminance contrast (experiments 3 and 4). In chapter 4, no interference effects occurred. However, a between-experiments comparison between the IS experiment in chapter 4 and the HI experiment in chapter 3 with the corresponding luminance contrast (experiment 3) revealed significant interference effects for both dark H/S and bright I. The analysis collapsed over letters (chapter 5) revealed significant interference effects on the global level that were independent of luminance both between experiments and within experiments. On the local level, the analysis collapsed over letters (chapter 5) revealed no significant interference effects for the experiments with rather high luminance contrast (experiments 1 and 2). In contrast, for the experiments with rather low luminance contrast (experiments 3 and 4), significant interference effects occurred. However, for dark dots, a significant reverse interference effect occurred for experiment 4 (lowest luminance contrast).

7.2.1 Global vs. local task

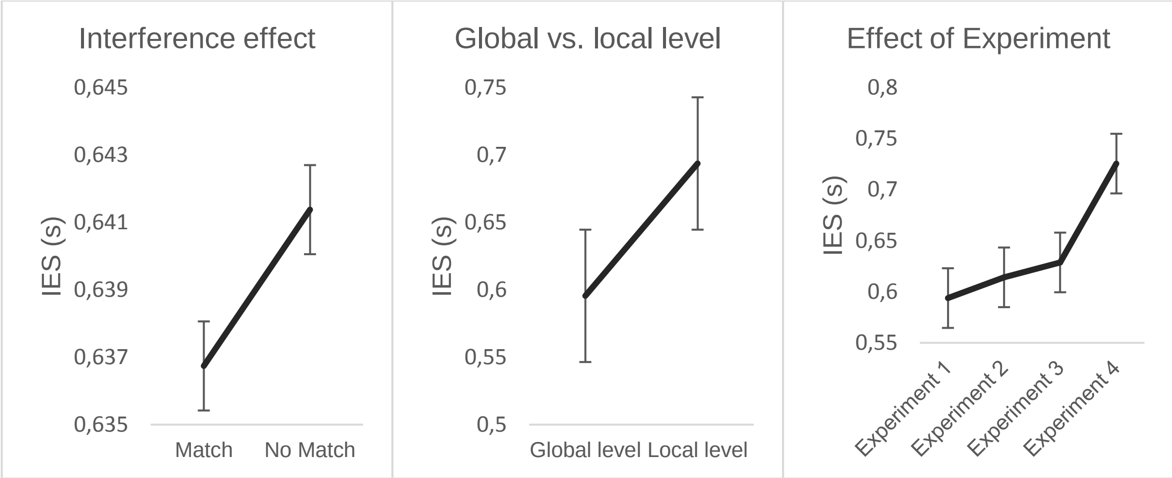

Figure 41: Combined results of global and local letter experiments
Illustration of the results of the analysis of the global and local level experiments based on the different experiments and matching vs. nonmatching conditions. Participants responded faster on the global level, for matching conditions and response times increased with decreasing luminance contrast.

Looking at the illustration of the interference effects of chapters 2-4 (figure 40), it can be shown that the interference effect was reliable in 5 out of 16 independent contrasts in the global level task (chapter 2). For the local level task (chapter 3), the interference effect was reliable in 2 out of 16 independent contrasts. While these results are not overly convincing, the results collapsed over letters revealed a reliable interference effect, especially for the global level task (chapter 5, figure 40). On the global level, this interference effect was independent of the luminance responses (bright or dark) and of the luminance contrast manipulations (high or low). In contrast, on the local level (chapter 5, figure 40), an interference effect only occurred for experiment 3, the condition with the second-lowest luminance contrast. It could be speculated that on the local level, interference effects are dependent on luminance contrast and only occur for one specific luminance contrast. This could be explained with the bottleneck theory (Broadbent, 1958). A bottleneck occurring for this specific luminance contrast could be assumed that did not occur for any other luminance contrast. However, it remains unclear why this bottleneck might only have occurred for this specific experiment and not for the other experiments in this task. To compare both the global and the local level experiments together, a between-experiments was conducted in chapter 5, where the analysis was collapsed over letters and over luminance responses (bright and dark). This analysis revealed important insight: independent of whether participants' attention was directed to the global or to the local level, they performed better for congruent conditions. These results, illustrated in figure 41, suggest that participants took both the global and the local letters into account, independent of the level their attention was directed to (global or local). Participants also performed the better the higher the luminance contrast, supporting previous findings (Plainis, & Murray, 2000; Walkey et al., 2006). Finally, they performed better on the global level, suggesting global precedence (e.g. Hughes et al., 1984; Navon 1977; 1981; Paquet, & Merikle, 1988). This global precedence effect already occurred in the standard Navon task that was conducted at the very beginning (see chapter 2, experiment 1). The interference effect seems to be particularly consistent if the analysis is averaged across the different letters and luminance responses.

7.2.2 Influence of letter identity

The majority of studies investigating the Navon effect collapse across letter identity and simply compare congruent vs. incongruent responses (e.g. Grice et al., 1983; Martin, 1979; Navon, 1981). No studies could be found that investigated the effects of different task-irrelevant letter identity. In the present work, we found reliable differences in interference between different letters, especially in the local level task (chapter 3). The influence of letter identity on task-irrelevant interference effects is a novel finding.

First of all, the standard Navon task was conducted in chapter 2 in order to find out whether the letters that were used in this thesis, H and I, cause interference effects. Two standard findings could be confirmed: participants were faster on the global level and they were faster for congruent stimuli (e.g. Navon, 1977; 1981). However, the interference effects were not independent of letters: for H, interference effects occurred on both the global and the local level, whilst for I, they only occurred on the local level. Nevertheless, the letters were regarded as sufficient to cause reliable interference effects. When rendering the Navon letters task-irrelevant in the global level task in chapter 2, interference effects occurred for the letter H and for a bright I in experiment

2. In contrast, in experiment 3, interference effects only occurred for the letter I but not for the letter H anymore (figure 40).

In the local level task (chapter 3), interference effects seemed to be more dependent on specific letter identity, as they never occurred for the letter H. In fact, in experiment 4, the condition with the lowest luminance contrast, reverse interference effects occurred for global H: participants performed significantly better for a local I than for a local H. In contrast, for the letter I, significant interference effects occurred. For experiment 1, the condition with the highest luminance contrast, those interference effects occurred for both bright and dark dots, but only for RTs, not for IES. Interference effects occurred for IES for experiments 3 and 4, the conditions with lower luminance contrast. However, it has to be mentioned that here, interference effects only occurred for bright I and not for dark I (figure 40).

All in all, the results of the local level task are apparently contrasting the standard Navon task that was conducted in chapter 2, where interference effects occurred on both levels for H but only on the global level for I. Considering that interference effects only occurred for a global I but not for a global H in the local level task, two alternative explanations were proposed. First, embedment of dots might have driven the interference effect, although this would only have been the case for bright and not for dark dots. Embedment of dots was given as one possible explanation as in a global H, the dots were embedded horizontally, whilst in a global I, they were embedded vertically. This might have led to better performance for global H, considering that performance is usually better on the horizontal than on the vertical (e.g. Collewijn, & Taminga, 1984; Ingster-Moati et al., 2009; Schmidt et al., 1993; Yu et al., 2010). It is therefore possible that performance for the global letter was the main determinant of performance irrespective of the identity of local letter. Second, the special characteristics of the letter H and I might have influenced interference effects, due to the Gestalt grouping principle of shape similarity (e.g. Rock, & Palmer, 1990; Wertheimer, 1923). It is possible that grouping was stronger for a global I than for a global H, which in turn led to interference effects for a global I but not for a global H. Lateral masking, which states that humans have difficulties to identify identical or similar forms in close proximity (e.g. Bouma, 1970; Mackworth, 1965; Wolford, & Hollingsworth, 1974) could be given as another explanation. It is important to mention that the letter I as used in this thesis could be seen as a rotated version of the letter H. Literature search gives mixed evidence about the effects of rotated letters on lateral masking effects. There is evidence that rotation of letters does neither improve nor impair performance (Huckauf et al., 1999) but there is also evidence that participants respond faster to letters than to rotated letters and importantly, that a congruency effect can occur for rotated letters but not for not rotated letters (van Leeuwen, & Lachmann, 2004). The results could also be explained with the Attentional White Bear theory (Tsal, & Makovski, 2006), which suggests active processing of distractors. According to this theory, attention is guided to all possible stimulus locations, independent of task demands. It is possible that this process happened in the local level task in chapter 3. For the letter I, the local and global letters (which can be referred to as distractors) were processed, while the global and local letters were not processed when the global letter was an H. Additionally, the different locations of the dots for the letters H and I guided attention, which can be explained by the Attentional White Bear theory as well, because in the original experiments (Tsal, & Makovski, 2006), distractors appeared at expected or unexpected locations and it was concluded that attention was allocated to expected distractor locations. The changing of the locations of dots means that locations changed from expected to unexpected and participants might have directed their attention to locations where they expected the dots to appear, even if the dots in this task were the targets and not the distractors.

In order to investigate the influence of task-irrelevant letter identity in a local level task further, another local level task with the letter S was conducted. The reasoning for choosing this letter was that it had the same embedment of dots as the letter H, namely on the horizontal. At the same time, the characteristics of the letter S that was used in this experiment meant that it had similarities with H but also with I, considering that both letters I and S that were used in this thesis can be seen as rather atypical representatives of the alphabet. In the first experiment, the letters H and S were used, which means that the dots were embedded consistently on the horizontal. No interference effects occurred. In the second experiment, the letters I and S were used, meaning that both letters were now bordered horizontally at the top and at the bottom. Again, no interference effects occurred (figure 40). It is somewhat surprising that this time, no interference effects occurred for I anymore, suggesting that interference effects might not be that dependent on the letter I as previously assumed. One possible explanation for this result could be that the letter I might only cause better performance for matching conditions if it is paired with a typical letter, i.e. H. If it is paired with an atypical letter like S, no interference effects might occur. In order to account for any effects of letter identity, a between-experiments analysis was conducted on the IS experiment and the HI experiment 3, because both experiments had the same luminance level. Interference effects occurred for a bright I, but only for the HI experiment, supporting the previous interpretation that interference effects only occur for the letter I if it is paired with a typical letter. Alternatively, it is possible that interference effects for the letter I just occurred due to chance. All in all, the results suggest that letter identity had much stronger effects in the local level task than in the global level task. For the global level task (chapter 2, figure 40), interference effects occurred for both letters H and I, whilst for the local level task, interference effects occurred for a global I and for a dark H/S in the between-experiments comparison in chapter 4 (figure 40). This difference in the interference effect based on letter identity probably occurred because of the task requirements of the local level task asked participants to focus on one dot in one specific local letter. However, it has to be mentioned that the differences in letter identity for the global and the local level task were not compared with each other in a statistical test.

The analyses and interpretation of the results of the global and local level experiments (chapters 2, 3 and 4) focused very much on how letter identity might have influenced the interference effects. While insightful, splitting up the analysis into different letters might have complicated the whole analysis. To simplify the analysis and to increase power, an additional analysis was conducted on the experiments of chapters 2 and 3, where the different letter identities were not taken into account and just interference (match vs. no match) and luminance were analysed (chapter 5). Analysing the results this way, for the global level experiments (chapter 2), interference effects occurred for all four experiments (figure 40). For the local level experiments (chapter 3), interference effects only occurred for experiment 3 and a reverse interference effect occurred for dark dots for experiment 4 (figure 40). The reverse interference effect was also found for the letter H in experiment 4 in chapter 3. The general interference effect that occurred in experiment 3 likely stems largely from the results in chapter 3, where an interference effect occurred for bright I in experiment 3. Previous results from chapter 3 could be also confirmed: no interference effects occurred for experiment 1 and 2, the conditions with rather high luminance contrast between the dots when the analysis is done based on IES.

7.2.3 Time-course effects

7.2.3.1 Time-course effects between experiments

When rendering the Navon letters task-irrelevant, there were no significant interference effects for the highest (experiment 1) nor the lowest luminance contrast (experiment 4) in the global level task in chapter 2. This seems to be contrasting the cognitive control theory, according to which interference effects should have occurred for the experiment that should have elicited fast responses, i.e. the highest luminance contrast (Bialystok et al., 2004; Coderre, & van Heuven, 2014; Jansma et al., 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984; Shiffrin, & Schneider, 1977; Stuss et al., 2001; White et al., 2018). However, the results confirm the prediction that no interference effects should occur for the experiment with rather slow responses, i.e. lowest luminance contrast. Additionally, the results seemed to be in line with the reverse U-shape prediction of the bottleneck theory (Pashler, & Johnston, 1988). For experiments 2 and 3, there were significant interference effects (figure 40). The absence of interference effects for the highest luminance contrast condition and for the lowest luminance conditions was explained by two different theories. For the highest luminance condition, it was explained by attentional capture (e.g. Theeuwes, 2004; Yantis, 1993). Attentional capture means that attention is involuntarily directed towards a stimulus based on its characteristics (Yantis, & Jonides, 1984), which can be for example the saliency of the stimulus. For the highest luminance contrast condition, this would mean that attention was captured by the luminance of the letters and consequently letter identity was not processed. For the lowest luminance contrast condition, the absence of interference effects was explained by the additional attentional resources that were needed in this condition, as the discrimination of bright and dark stimuli should be the most difficult in this condition. This can be combined with the perceptual load theory (Lavie, 1995). It states that for conditions with high perceptual load, the target will be selected quickly and the distractors will be filtered out, because of the attentional resources that are needed in those conditions. However, in conditions with low perceptual load, fewer attentional resources are needed, which in turn can lead to the processing of distractors and can cause interference. It is important to mention that the time-course manipulation through the different luminance contrasts between experiments was not successful, as there was no main effect of experiment. It can be speculated that the time-course manipulation of the different experiments was not successful because the global level task was overall easier than the local level task, which can be supported by the fact that RTs for the global level task were shorter than for the local level task (figure 41). This supports the global precedence effect (e.g. Hughes et al., 1984; Navon, 1977; 1981; Paquet, & Merikle, 1988). Considering that RTs were overall relatively short for the global level task, the different luminance manipulations between experiments might not had strong effects.

The results of the local level task (chapter 3) between experiments cannot be explained with the time-course prediction of the cognitive control theory, as no interference effects occurred for the experiments with higher luminance contrast but interference effects occurred for experiments with lower luminance contrast. This contradicts the prediction that interference effects should occur for fast but not for slow responses (Bialystok et al., 2004; Coderre, & van Heuven, 2014; Jansma et al., 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984; Shiffrin, & Schneider, 1977; Stuss et al., 2001; White et al., 2018). There is also a lack of evidence for the time-course prediction of the bottleneck theory between experiments. The reverse U-shape prediction of the bottleneck theory (Pashler, & Johnston, 1988) could not be confirmed, as the luminance manipulation of the time-course of the different experiments was only partly successful. Performance was best for the experiment with the second-highest luminance contrast and not for the experiment with the highest luminance contrast. It is important to note that participants were overall faster for experiment 2 than for experiment 1, which contradicts our predictions that participants should be better for higher luminance contrast (Plainis, & Murray, 2000; Walkey et al., 2006). Participants were also slightly more accurate for experiment 2 than for experiment 1. This result might have occurred because the condition with the highest luminance contrast facilitated the discrimination of the different contrasts and in turn led to a loss in accuracy. The results of both RT and accuracy led to a better performance (reflected in IES) for experiment 2 compared to experiment 1. Additionally, according to the reverse U-shape prediction, interference effects should not have occurred for the experiments with the highest and the lowest luminance contrast but for the other experiments. This was not the case, as interference effects occurred for all experiments apart from experiment 2, the condition with the second-highest luminance contrast. It has to be mentioned that these findings contradict the findings from chapter 2, where no interference effects occurred neither for the highest nor for the lowest luminance contrast condition.

In conclusion, the time-course manipulation of interference effects between experiments was not successful. Although for both the global level task (chapter 2) and the local level task (chapter 3), interference effects only occurred for specific luminance contrasts (figure 40), these results cannot be really explained by time-course between experiments, considering that the luminance contrast manipulation did not reliably affect RTs across the different experiments. In addition, the analysis collapsed over letters (chapter 5) revealed that for the global level task, interference effects occurred independent of the different luminance contrast manipulations (figure 40). This can be also supported by the analysis where the global and the local level task were both compared (figure 41).

7.2.3.2 Time-course effects within experiments

The luminance response manipulation (bright or dark) enabled to manipulate time-course within experiments and to test the time-course predictions of the cognitive control theory and the bottleneck theory within experiments. When looking into the speed of RTs within each of the individual experiments in chapter 2, it seemed to be the case that interference effects occurred for conditions where responses were rather fast within each experiment, which would be in line with the prediction of the cognitive control theory (Bialystok et al., 2004; Coderre, & van Heuven, 2014; Jansma et al.; 2001; MacLeod, 1991, Payne, 2001; Schneider et al., 1984; Shiffrin, & Schneider, 1977; Stuss et al., 2011; White et al., 2018). This could also be confirmed in the between-experiments analysis, where interference effects occurred for conditions that were numerically responded to relatively fast (i.e. dark H and bright I) but not for conditions that were responded to more slowly (i.e. bright H and dark I). However, there was a lack of statistical support for the differences in time-course for the conditions where responses seemed to be fast compared to conditions where responses seemed to be rather slow.

The results of the local level task when testing for the time-course of interference effects within experiments were contradicting the cognitive control theory, as interference effects occurred for the condition with rather slow responses, i.e. bright I. However, this result was in line with experiments that showed that interference effects can increase as response times increase (Bub et al., 2006; Cohen et al., 1990; Glaser, & Glaser, 1982, van Zoest et al., 2012), considering that responses were slower for I than for H. It has to be mentioned that like in chapter 2, the effects of speed for the different conditions within experiments were not statistically significant.

When looking into the time-course of the local level task, it is also important to note that there was a speed-accuracy trade-off in experiments 2 and 3 and in some conditions in experiment 4 in chapter 3: participants were slower but more accurate for bright dots. Therefore, the IES was calculated. This speed-accuracy trade-off probably occurred because the whole letter was presented against a white background, rendering the discrimination of the bright dots more difficult (e.g. Buchner, & Baumgartner, 2007; Komban et al., 2001). Only in experiment 1, there was no speed-accuracy trade-off, probably because the luminance contrast was the highest in this condition. In experiment 4, the condition with the lowest luminance contrast, there was no main effect of luminance on RTs (with participants not being faster for dark dots anymore in this condition), probably because the discrimination of both bright and dark dots was the most difficult in this experiment.

In chapter 4, a between-experiments analysis was conducted to compare the HI experiment 3 from chapter 3, which had the same luminance contrast as the experiments in chapter 4, and the IS experiment. The results suggest that interference effects cannot be solely explained with letter identity, as interference effects occurred for a bright I but also for a dark H/S (figure 40). This leads to the suggestion that on the local level, interference effects seem to occur when performance is rather worse and responses are rather slower than in other conditions (as it is the case for bright I) or contrary, performance seems to be better and responses are rather faster than in other conditions (dark H/S). However, the fact that interference effects occurred for both bright I and dark H/S might also show that interference effects are simply not very consistent in a local-level task-irrelevant Navon experiment. It would also contradict the explanations of attentional capture (e.g. Theeuwes, 2004, Yantis, 1993) for tasks that should be relatively easy and of additional cognitive resources for tasks that are relatively difficult (e.g. Lavie, 1995). Both attentional capture and the need of cognitive resources would explain the lack of interference effects for easy and difficult conditions. However, the results of this between-experiments-analysis in chapter 4 contradict exactly these explanations, considering that interference effects occurred for the condition that seemed to be the easiest when looking at response times and performance (dark /S). Similarly, interference effects also occurred for the condition that was most difficult when looking at response times and performance (bright I). It is again important to mention that like in the previous chapter, a speed-accuracy trade-off occurred for both experiments in chapter 4, with participants being again slower but more accurate for bright dots, so the IES was calculated again.

In conclusion, the time-course manipulation of interference effects within experiments was not successful. Although interference effects only occurred for certain conditions (i.e. bright I in the local level task in chapter 3), these results cannot be explained by time-course within experiments. Additionally, the luminance response manipulation was only partly successful. Whilst there were differences for bright vs. dark responses in the global level task (chapter 2), the predictions for the differences in responses for dark vs. bright targets could also only be partly supported for the local level task (chapter 3). Whilst dark dots were responded to faster, they were not responded to more accurately, which resulted in a speed-accuracy trade-off and contradicts our hypothesis that dark dots should be responded to more accurately (e.g. Buchner, & Baumgartner, 2007; Komban et al., 2001).

In chapter 6, the time-course of task-irrelevant automatic interference effects on the local level within experiments was investigated by measuring participants' reaching movements. There were no interference effects neither for IL nor for MD. However, for the local letters I and S, there was a significant main effect of luminance on IL. Participants needed longer to initiate the movement when the dots were bright, which confirms previous RT results on the local level, where responses were longer for bright dots (chapters 3 and 4).

7.2.3.3 Time-course effects bins

Although the results collapsed over both letters in chapter 5 suggested that speed of responding had less strong effects as previously assumed, it was suggested that within each experiment, fast and slow responses might have been modulated differently by the irrelevant letter identity (van Zoest et al., 2012). Therefore, the response times were allocated into ten different bins, from fastest to slowest responses, which enabled to examine the time-course within each experiment. In addition, the outlier removal procedure was changed. Whilst previously, outliers were removed based on SDs around the overall mean, now outliers were removed based on SDs around the individual mean of each participant in order to focus on within-subject variability in contrast to between-subject variability. If there was an interaction of interference and bin, this would provide statistical support that the occurrence of interference effects depends on the speed of responses. However, this interaction of interference and bin was not significant neither on the global nor on the local level. Nevertheless, main effects of interference still occurred on the global level, whilst on the local level, interference effects were dependent on experiment. The results of this analysis suggest that although speed of responses has been proposed as an explanation before, a statistical analysis does not stand up to the explanation that interference effects in task-irrelevant Navon stimuli are dependent on speed. Accuracy was also analysed with the new outlier removal procedure in order to establish whether speed-accuracy trade-offs still occurred. Whilst there was still no speed-accuracy trade-off on the global level, it still occurred on the local level, suggesting that both outlier removal procedures lead to similar results. One important difference is that on the local level, there was now a main effect of interference when the IES was calculated with the new outlier removal procedure and there were no interactions with experiment anymore. Previous results could be replicated, such as better performance for dark dots and the differences in performance for the individual experiments. Therefore, it can be concluded that both outlier removal procedures could be used but results are more reliable when outliers are removed based on the SD of each individual participant, as they lead to a main effect of interference on the local level when looking at the IES. It is possible that there was more variability in performance for the local level task than for the global level task and this might explain the difference in results depending on which outlier removal procedure is chosen.

7.3 Implications and limitations of this thesis

This thesis gave important insight into task-irrelevant letter processing on both the global and the local level. The results suggest that independent of whether participants were performing a global or a local level task, they took the combination of letters into account. This can be mainly concluded from the final analysis collapsed over letters and luminance responses (figure 41), which showed that participants responded faster to matching conditions, independent of attentional focus. This interference effect might have occurred because participants grouped the local stimuli to a global stimulus (e.g. Koffka, 1935; Rock, & Palmer, 1990). It seemed to be independent of the task- whether participants' attention was directed to the global or to the local level. It could be also assumed that interference effects occurred because of stimulus-stimulus compatibility (SSC, Kornblum, 1992). According to SSC, responses are faster when two stimulus dimensions are compatible than when they are not compatible. Importantly, Kornblum (1994) predicted that those interference effects can occur when both task-irrelevant stimulus dimensions overlap with each other and the task-relevant stimulus dimension only overlaps with the response. This was the case for the stimuli used in this thesis. However, it is important to note that the global level task also invoked local processing mechanisms and vice versa, the local level task invoked global processing. In the global level task, not jittering the hierarchical letter position may have biased local instead of global processing. Although it was assumed that participants would complete the task using global processing, it is equally possible that participants generally favoured local processing mechanisms by just focusing on one local letter. Equally, in the local level tasks in chapters 3 and 4, the global letter configuration is confounded with the local target positions of the dots. This implies that global processing might have occurred as part of the task demand.

It is not entirely clear whether this thesis supports the assumption that cognitive control is needed for the successful suppression of interference effects (e.g. Derfuss et al., 2004; MacLeod, 1991). There was no investigation of automatic vs. controlled processes in this thesis and therefore it is not clear which type of process was used by the participants when completing the experiment. It could be assumed that participants most likely only used automatic processing, considering that they were only instructed to respond to the luminance of the letters/dots and the only controlled process that was used by the participants was most likely discriminating the location of the dot and discriminating whether the letters/dots were brighter or darker, particularly in the conditions with low luminance contrast. When talking about cognitive control, the Stroop effect is often taken as a famous example (e.g. MacLeod, 1991; Posner et al., 2004), but there are key differences between the Stroop task and our task. Whilst in the Stroop task, participants clearly have to suppress the automatic activation of the word (MacLeod, 1991), it is not clear whether the letters were automatically activated in our task and whether participants in turn had to cognitively suppress incongruent letters. The overlap of luminance and letter identification might not have been big enough to trigger cognitive control processes. In line with the Attentional White Bear theory (Tsal, & Makovski, 2006), it could be equally assumed that instead of automatic processing, active attentional processing of the distractors (i.e. the letters) took place.

The question whether a bottleneck occurred in the series of experiments used in this thesis or not cannot be fully answered. As the luminance manipulation did not work out in the way it was expected in the sense that performance was not constantly best for the highest luminance contrast and worst for the lowest luminance contrast, it cannot be said that a bottleneck occurred for a certain luminance contrast and not for other luminance contrasts. It is also possible that the processes of luminance detection and letter identification differed too much to lead to the occurrence of a bottleneck and that completely different visual attention mechanisms were involved in those two processes. It would have been necessary to find out whether luminance detection and letter processing are two independent processes that are still similar enough to lead to the occurrence of a bottleneck. This could have been tested by using two independent tasks for luminance detection and letter identification and manipulating the SOA interval, as it is usually the case in dual-tasks experiments that test the bottleneck theory (e.g. Pashler, & Johnston, 1989; Pashler, 1994). Manipulating the SOA interval would have given insight into the question whether interference effects only occur in a certain time-frame. The rationale for this experimental manipulation is given by studies where the SOA interval between colour and word was manipulated in the Stroop task (e.g. Appelbaum et al., 2012; Dyer, 1971; Glaser, & Glaser, 1982; Lu, & Proctor, 2001; Roelofs, 2010; Starreveld, & La Heij, 2017), which directly tests the bottleneck theory (Broadbent, 1958). The manipulation of the SOA interval might have been particularly relevant considering that May et al. (2009) found that delaying global information relative to local information affects the time-course of interference effects, as they only occur in certain time-frames.

Another question that could not be satisfyingly answered was the lack of occurrence of interference effects in task-irrelevant stimuli when using the choice reaching task (CRT, chapter 6). It is possible that task-irrelevant interference effects in Navon stimuli are only reflected in RTs. However, it is important to note that in the CRT, task-irrelevant interference effects were not reflected in IL, which represents RTs when reaching movements are measured. Looking at the CRT experiments, it needs to be mentioned that the number of participants was relatively small, therefore further research is needed in order to answer the question whether task-irrelevant local level processing might be reflected in reaching movements or not.

Nevertheless, despite all the limitation of this thesis, it is an important finding that task-irrelevant interference effects can occur for both global and local level tasks when using the Navon task and measuring RTs. Considering that these interference effects occurred relatively reliably (figure 41), it can be assumed that participants processed the task-irrelevant letters. The fact that task-irrelevant interference effects occurred in the Navon task is particularly important considering that the Navon task reflects visual scene processing, particularly human’s ability to perceive the whole of a scene as well as its local parts (e.g. Baisa et al., 2019; Chamberlain et al., 2017).

7.4 Suggestions for further research

7.4.1 Issues with the effect of letter identity

Although the results of this thesis showed that automatic task-irrelevant interference effects occur on both the global and the local level, there are still many unanswered questions. Further experimental manipulation might have been more insightful. For example, we could have done a standard Navon task using the same letters as used throughout these experiments (H and I), i.e. asking participants to respond to the global and to the local letter. This task was conducted in the first experiment in chapter 2, but we could have used the standard Navon task in combination with the luminance-response task throughout all experiments, in a within-participants design. The obtained measures of interference could have been used to correlate the standard Navon task with the performance in the luminance-response task. It might have been also a good idea to include some neutral trials, for example shapes that form a global letter and local letters that form a global shape. Generally, it would have been beneficial if shapes had been used as well because many explanations concerning the differences in the interference effects focused on the different letter identities, so it would have been beneficial to find out whether Gestalt grouping might also occur if shapes instead of letters are used. Participants could have been also encouraged to actively process the letter, even if it was not task-relevant. We could have used a similar design as van Zoest et al. (2012), who tested stimulus-response compatibility (SRC) by asking participants to respond to the presence of a singleton arrow by responding with their right index finger or to the absence of the arrow by responding with their left index finger. The direction of the arrow could be compatible or incompatible with the right hand. A stimulus-response compatibility (SRC) effect only occurred when participants were actively encouraged to process the arrow's pointing direction. In our experiment, we could have used a similar manipulation by introducing blocks of trials, where participants would have been asked to respond to the global or to the local letter identity in-between the luminance discrimination tasks.

7.4.2 Issues with the experimental manipulation of luminance detection

It is important to note that the potential confounding effects of letter identity and luminance detection cannot be always viewed at separately, especially in the global level task (chapter 2). Nevertheless, there were some difficulties in explaining the results of this thesis, which probably occurred due to problems with the luminance response manipulation.

Considering that the luminance of the letters/dots (bright or dark) had a strong effect on performance, particularly in the local level tasks, where it caused a speed-accuracy trade-off, it would have been also useful to change the background and run half of the trials with a white background and the other half with a black background. The aim would have been to find out if the speed-accuracy trade-off could be reduced and whether this in turn would influence the interference effect, considering that it only occurred for a specific luminance response in the local level task in chapter 3 (i.e. bright I). Furthermore, it would have been useful to examine automatic processing in another way than only asking participants to detect the luminance of the letter or dot. This could have been for example implemented by asking participants to respond to the location of the dot, which would have directly addressed the problem of the different dot positions in the local level task, as participants would have been instructed to actively process those locations. If this experimental manipulation had been used, unintentional overlap in terms of SRC (Kornblum, 1992) could have been reduced. This unintentional overlap occurred when participants were asked to respond to a dark dot in a global I by pressing the letter ‘m’ on the computer keyboard or vice versa, when participants were asked to respond to a bright dot in a global I by pressing the letter ‘k’ on the computer keyboard. However, the manipulation of responding to the location of the dot could not have been implemented in the global level task.

7.4.3 Widening of the research question and suggestions for further experimental manipulation

It would have been also good to combine global and local processing in the CRT by manipulating both global and local attentional focus in order to see whether task-irrelevant interference effects occur in one condition but not the other. This would have been particularly relevant as McCarthy and Song (2016) showed that a task-irrelevant global figure can delay the initiation of the movement. Other possibilities to get additional insight in the underlying processes could be by using in future not only behavioural data or the CRT. Especially electroencephalography (EEG) data might be helpful. Importantly, 0 SOA (simultaneous presentation of colour and word) has been linked in EEG to the negativity associated with incongruency (N_{inc}) in the Stroop task. N_{inc} is a conflict-related ERP component that occurs from approximately 300-500 ms after the onset of conflict (Coderre, & van Heuven, 2014). It might have been beneficial for this series of experiments if EEG measures had been done as well. If for incongruent Navon stimuli a N_{inc} occurred as well, despite the Navon stimuli being task-irrelevant, this would give additional insight into interference effects and their detection.

7.5 Conclusion

This thesis investigated task-irrelevant global and local processing by using the Navon task and asking participants to respond to the luminance of the letter or dot in order to render the letter task-irrelevant. The first analyses were done based on the different letter identities and seemed to show that the occurrence of task-irrelevant interference effects depended on letter identity and speed of responses (chapters 2 and 3). However, the analysis averaged across the different letters revealed that task-irrelevant interference effects occurred, independent of letter identity and speed of responses. These interference effects were independent of whether participants' attention was directed to the global or the local level (chapter 5, see figure 41 for an illustration of the results). Those task-irrelevant interference effect could only be shown in RT tasks and were not replicated when the CRT was used (chapter 6).

There are some limitations to this thesis, such as that participants were not encouraged to actively process the different global and local letter identities. This experimental manipulation would have been particularly useful in order to distinguish the two processes of letter identification and luminance response. Some other suggestions for future research would be to actively manipulate the SOA interval of letter identification and luminance manipulation. The CRT should also be revisited by increasing the number of participants and by combining local processing with global processing. Finally, methods such as EEG could have provided additional insight into the underlying processes. In conclusion, it has to be mentioned that despite all its limitations, this thesis succeeded in showing insight into the occurrence of task-irrelevant interference effects in the Navon task, independent of attentional focus.

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