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**Irrelevant information processing:
inquiry into the validity of a neural-based
overlap model**

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o//o

Chapter 1

Introduction

“In cognitive psychology there are as much theories as researchers”

— R. Bootsma

“Probably even more”

— J. Allik

This thesis comprises several studies investigating the validity of a neural-based overlap model for irrelevant information processing. The second chapter contains the experiments that gave the initial impetus to our “neural overlap hypothesis”, as well as a number of experiments to rule out alternative accounts for the effects obtained. In a third chapter, we report experiments that employ a different type of stimuli but also support the neural overlap hypothesis. In Chapter 4 however, I gathered a series of studies that are not congruous with the notion of neural overlap. Finally, in a last chapter I will give an overview of the work done and discuss the viability of the neural overlap hypothesis as it is introduced in Chapter 2.

Because I do not want to repeat myself endlessly, it is not my intention to give a long in-depth introduction to the neural overlap hypothesis in this section. For specific details about the neural overlap hypothesis I refer to the second chapter, where it is discussed in greater detail. For now, I will try to

give a rough sketch of attention theories, focusing the way they encompass the processing of irrelevant information in particular. First, we will take a look at some of the earliest modern theories of attention. While these do not all deal with the problem of irrelevant information processing primarily, at least they do so implicitly. Second, I will talk about stimulus response compatibility theories, some of which touch explicitly on the fate of irrelevant information. Third, I will introduce some historical precursors of the neural overlap hypothesis, before I outline the scope of this thesis.

1.1 Theories of attention

“Everyone knows what attention is ...” (James, 1890). This phrase is probably the most frequent utilized quote in order to introduce the subject of attention. When James said that everyone knows what attention is he probably meant to say that each one of us intuitively can grasp the idea of what attention can mean to us. If you ask first year psychology students how they conceive attention, very often you get examples like “it allows us to stay awake during boring lectures”, or “it helps me to spot my boyfriend in a crowded railway station”, or else “it makes our eyes dwell to the icon in the bottom right corner of our computer screen when a blinking icon reminds us that a new message has arrived”. Although we all have a subjective feeling of what attention is, it is difficult to give a precise definition encompassing all its different aspects.

It is clear though that attention is not a unified concept but manifests itself in a number of different forms of attention. According to LaBerge (1995), attention serves three main functions, namely preparing the system for expected changes, selecting essential information above irrelevant information and exercising vigilance.

Another important distinction that is made in the literature when talk-

ing about attention, is whether attention is under voluntary control (active attention) or beyond the control of the human processing system (for instance when attention is “automatically” oriented towards sudden events) (Kok, 2004). The active form of attention entails directing attention from within to the outside world. All sorts of stimuli, like sounds or images, can be the subject of active attention (although most theories of attention refer to visual attention). Somehow, actively attended stimuli are more apt to further processing while the processing of irrelevant or distracting stimuli is attenuated or even blocked.

Active attention mechanisms are further divided into two categories. On the one hand, it is possible to attend to different stimuli or tasks simultaneously by distributing attention over all those stimuli that need to be processed (divided attention). It is assumed that the amount of simultaneously attended stimuli or tasks depends on the available resources or processing capacity available. Selective attention on the other hand refers to our ability to process one stimulus while ignoring or inhibiting irrelevant material. Theories describing active selective attention typically contain a structural bottleneck in one or the other. This bottleneck is used for selecting the stimulus of interest for further processing, while putting a halt to further processing the irrelevant material. We will now discuss two different types of theories: Bottleneck theories, which can be placed in the active selective attention corner, and capacity sharing theories, which highlight active distributed attention.

1.1.1 Structural bottleneck theories

A recurring topic in theories of active selective attention concerns the question at what point in the information-processing flow the actual act of selection takes place. Is it at a moment relatively early after sensory information arrives in our system, or alternatively, does it take place relatively late there-

after?

Different views emerged on this topic during the history of cognitive psychology. At the opposite ends of the point-of-selection continuum, two extreme views can be found: the early selection theory and the late selection theory. Both viewpoints emerged during the 1950s and 1960s and inspired a great deal of work done afterwards. Although these theories are nowadays considered to be past their best, it is still essential to introduce them because they motivated a lot of research on attention during the last forty years. Therefore, the spirit of many studies is hard to grasp without knowing something about them (Pashler, 1998).

Early selection

The filter theory of Broadbent (1958) is one of the best-known modern theories of attention. Of paramount importance for this theory is the *selective filter* which constitutes a filtering device pointing out which stimuli need further processing based on simple physical attributes. Importantly, this filtering device was conceived to be capable of handling only one stimulus at a time. This means that all stimuli entering the attentional system are processed up to the point where a coarse physical analysis takes place. Then, based on the representations of these physical attributes one of the stimuli is selected for further processing and is subsequently identified. It is clear that according to this theory, irrelevant information is not likely to be identified or even represented beyond the level of simple physical characteristics because selection takes place in a processing stage relatively early after the stimuli entered the system.

Late selection

As opposed to the early selection theories, late selection theories assume that selection only takes place after all stimuli perceived simultaneously are com-

pletely analysed and identified. This idea was adhered by multiple theories of attention (e.g. Deutsch & Deutsch, 1963; Norman, 1968; Duncan, 1980) all sharing the same basic idea that recognition of familiar objects initially takes place unselectively and without capacity limitations. This means that in contrast with theories supposing early selection this account does not pose a limit to the number of items that can be processed simultaneously. The number of stimuli entering the system does not affect the extent by which these are analysed, nor does it have an impact on the time needed to analyse these items. However, once all stimuli are properly analysed and categorized, selective processing which is liable to capacity limitations does pursue. Furthermore, as Pashler (1998) pointed out, the assertion of late selection theories that stimuli are analysed independent of attention or capacity limitations does not necessarily mean that stimuli are identified without exception. Rather it should be understood that voluntary control will have no effect on whether or not foveal stimuli are identified. As pointed out before, late selection theories assume that all information entering the sensory system is processed and identified, including information that is irrelevant for the task at hand. This means that the selection process is based upon a consideration between the identity representations of both relevant and irrelevant stimuli.

1.1.2 Capacity sharing theories

Capacity sharing theories depart from two assumptions. First, they assume that the available amount of processing capacity is finite. Our system is limited in the amount of information that it can handle at once. Second, they also assume that available amount of processing resources is shared between the information units that need to be processed. In other words, capacity sharing theories start from the assumption that each unit entering the processing system receives some part of the available processing capacity. However, because the amount of processing capacity available is limited,

processing two items simultaneously will take longer compared to processing just one stimulus. As such, capacity theories of attention assign interference to a shortage of unspecified resources. This means that two tasks will interfere if their combined claim for resources exceeds the available capacity (McLeod, 1977).

Strictly spoken, the aforementioned bottleneck theories are also capacity theories because they imply structural restrictions on the amount of information that gets processed at once (be it early or late in the course of processing). However, the implementation of capacity limitations in bottleneck theories is implicit (the filter selects a stimulus and from that moment all resources are attributed to the selected one), while it is explicitly assumed in capacity theories.

A theory of attention related to the capacity sharing point of view is the filter-attenuation theory of Treisman (1960). According to this theory, rejected stimuli are not simply locked out from further processing but the resources spent on these are attenuated. This means that it is harder for unattended stimuli to be recognized, because their activity accumulates very slowly, making it difficult to be picked up by specific detector units. However, according to Pashler (1998) the implications of this filter-attenuation theory were never really clear. For instance, this theory provided no answers to questions like whether attending to multiple stimuli at the same time leads to the same amount of attenuation for all stimuli, regardless if they are relevant or irrelevant.

Capacity sharing theories do not explicitly handle the topic of irrelevant information. Resources are shared between items that need attention. As such, they all assume divided attention and not selective attention and they do not address the question if rejected stimuli also take capacity or not.

1.2 Stimulus response compatibility models of information processing

The attention theories discussed so far do not tell us much about the mutual relations between stimuli and responses. Stimuli are attended and selected according to the specific goal that is set, but typically they do not explicitly provide a forum for stimuli and responses to “communicate”. The first to recognize the importance of this stimulus-response relation were Fitts and Seeger (1953) who showed that human performance is not only affected by the characteristics of the stimulus set and response set used in a task, but also by the combination of the two. In their 1953 study, Fitts and Seeger showed that responses were faster and more accurate when the response-set arrangement corresponded to that of the stimulus-set (e.g. they were both horizontally oriented) compared to when this was not the case (e.g. stimuli were presented horizontally whereas response had to be given diagonally). Moreover, in 1954, Fitts and Deininger only employed circular stimulus and response sets, and varied the mapping between the stimulus and response sets. What they found was faster and more accurate responses for spatial compatible S-R mappings, than for spatially non-corresponding S-R mappings. Since then, the effect of overlapping features between stimulus and response was called the stimulus-response compatibility (SRC) effect.

A crucial moment in the history of SRC research was the finding of the Simon-effect which showed that correspondences between the stimulus and the response can affect performance even if this relation is completely irrelevant for the task at hand (see Simon, 1990 for a review). In a typical “Simon” experiment subjects have to respond to a non-spatial feature of a left or right presented stimulus by pressing left or right. The Simon effect is reflected in the finding that responding to (for instance) the colour of a stimulus that is presented on the left hand side will be faster using a left sided response com-

pared to a right sided response even though the position of the stimulus is completely irrelevant. From an information-processing perspective, this finding is peculiar. Why would information that is task-irrelevant be processed in such a way that it influences performance? A first attempt to explain this phenomenon was put forward by Simon himself (1969). He suggested that the tendency to respond towards the stimulus is the driving force behind this effect. Attention is forced into the direction of the stimulus, making it easier to make a corresponding response. This attentional perspective was quickly followed by a *coding* view. Coding accounts are different because they explain the whole range of SRC effects by considering the way how stimuli and responses are coded and how these code representations interact during the transition from stimulus to response (e.g. Wallace, 1971, 1972). With regard to the example that was given previously for the Simon effect this means that both the irrelevant stimulus position and the response are coded as “right”. This facilitates performance because the response expected for the relevant stimulus attribute corresponds with the code associated with the irrelevant stimulus position. No such facilitation or even interference is expected however when the irrelevant stimulus position points to a code different from the expected response.

In the beginning, SRC studies primordially aimed at localizing the stage in the information-processing stream at which compatibility effects emerge. The three stages considered were (a) the perceptual stage responsible for stimulus processing, (b) the stimulus-response (S-R) translation stage that uses the output of the perceptual stage to activate the corresponding response, and (c) the response stage taking care of action control; e.g. Meyer & Kieras, 1997; Pashler, 1994; Sanders, 1980; Sternberg, 1969; Welford, 1952).

From the nineties on, however, SRC research saw some major changes (Hommel & Prinz, 1997). Instead of concentrating on the locus of compatibility effects, more energy was put in specifying the mechanism behind

them. One of the most influential models that came out of this period was the dimensional overlap model of Kornblum, Hasbroucq, and Osman (1990).

1.2.1 Kornblum's dimensional overlap model

In 1990, Kornblum et al. introduced the dimensional overlap model. This model was constructed to provide a unified account and taxonomy for stimulus-stimulus (S-S) and stimulus-response (S-R) compatibility effects.

The key concept behind this model is that the way and the speed by which a stimulus is translated into a response depends on the relation between the dimensions of stimulus and response. More specifically, compatibility effects are caused by *dimensional overlap* between the stimulus and the response sets, and/or mutual dimensional overlap between relevant and irrelevant stimulus components. Of course, the assumptions made by the dimensional overlap model completely depend on what is understood by dimensional overlap. After the initial introduction of the model in 1990, Kornblum (1994) defined dimensional overlap as the degree to which the mental representations of relevant and/or irrelevant stimulus sets are perceptually, conceptually, or structurally similar to the response set codes and/or to each other. Later, Kornblum and colleagues mentioned that although similarity is a continuously varying quantity, it is treated discretely (see Kornblum, Stevens, Whipple, & Requin, 1999, footnote 1). This means that, although in essence similarity is a parametric property, it is considered as a discrete one in the context of the dimensional overlap model. Either the stimulus and/or response sets dimensionally overlap, or they do not. Of course, this does not take into account on what point on the similarity continuum no overlap is turned into a complete overlap. Additionally, the theory does not provide parametric measures to predict the sizes of the compatibility effects

Of peculiar importance for the dimensional overlap model is the explicit role of irrelevant information. From the processing assumptions behind it

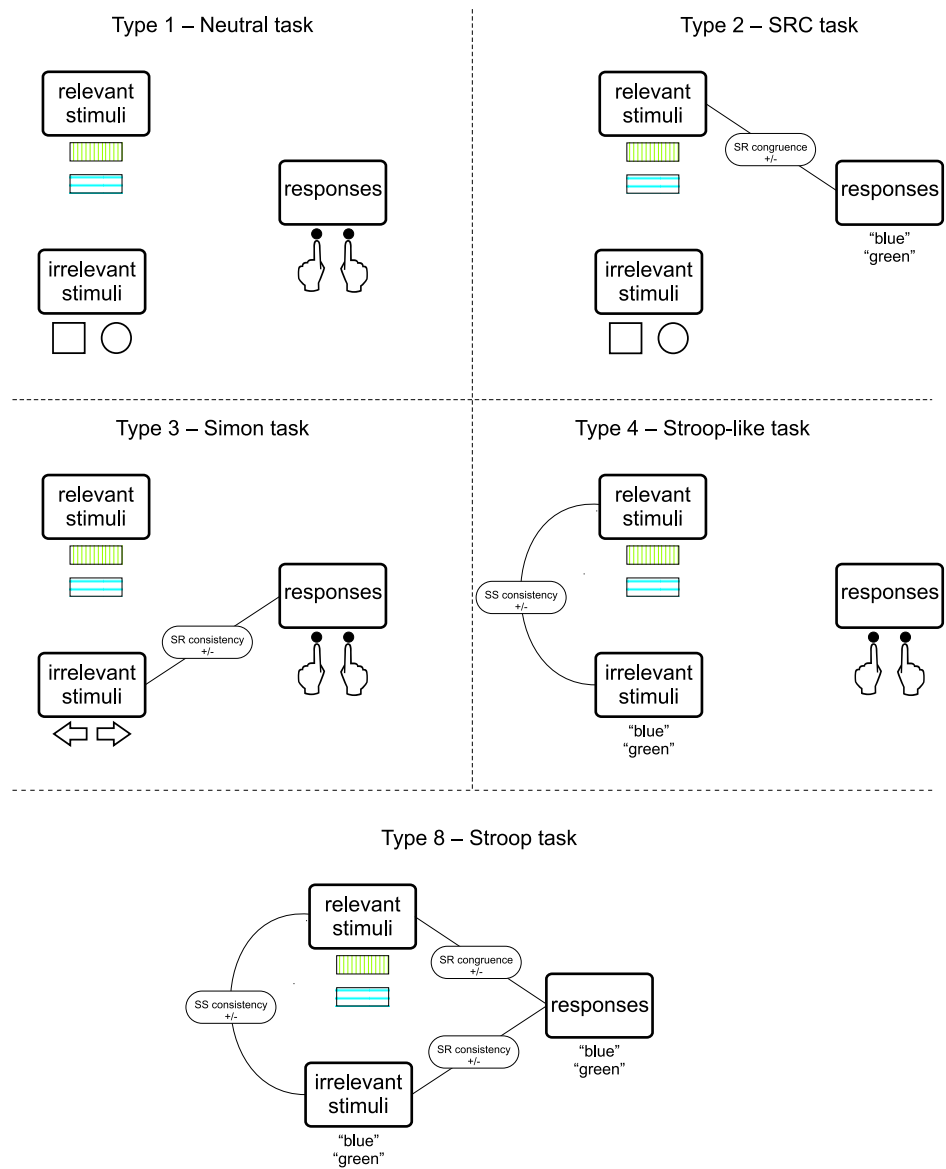


Figure 1.1: Selection of dimensional overlap ensembles specified by the dimensional overlap taxonomy. Dimensional relationships between the relevant stimuli, irrelevant stimuli and the responses are indicated by a line joining the overlapping sets. Adapted from Kornblum and Stevens (2002).

follows that dimensional overlap influences performance, irrespective if the dimensions involved are irrelevant or not. For example, if the irrelevant stimulus dimension overlaps with the response, this congruency results in facilitated responses (e.g. the Simon effect).

In total, the dimensional overlap taxonomy consists of eight S-R ensembles, each resembling one of the possible dimensional overlap combinations between the relevant stimulus, the irrelevant stimulus and the response (See Figure 1.1 for a subset of examples). These different ensembles simplified the way how to address different types of S-R relations. For instance, under this taxonomy Type 2 ensembles denote simple SRC events with compatibility between the relevant stimulus and the response. In another example, the Simon effect is categorized under the Type 3 denominator.

The reason for this is that the S-R relations for the Simon effect are restricted to dimensional overlap between the irrelevant stimulus and the response only (S-R consistency). There is no overlap between the relevant stimulus and the response (S-R congruency), nor overlap between the relevant and irrelevant stimulus attributed (S-S consistency)¹.

There are some manifest advantages associated with adopting the dimensional overlap taxonomy. Not only does it provide a simple terminology and system for describing stimulus-response compatibility effects like the Simon effect, but it also allowed researchers to develop new predictions for compatibility effects between stimulus and response sets that were previously not considered. One of the main assets, however, of this taxonomy was that it provided a prominent role for irrelevant information in the S-R translation process.

¹In Kornblum and Lee (1995) the idea was proposed to use *congruency* when the relevant stimulus and response dimensions overlap, as opposed to *consistency* which should be used when the irrelevant stimulus and response dimensions overlap.

1.2.2 Dual Route model

The underlying basis of the dimensional overlap model (Kornblum et al., 1990) consists of two pathways, each connecting respectively relevant and irrelevant information with the response. Furthermore, the dimensional overlap model implies that a stimulus is automatically mapped onto its corresponding response code, at least if the stimulus information dimensionally overlaps with the response.

Hasbroucq and Guiard (1991) questioned the necessity for an automatic activation account. Based on the results of a series of irrelevant SRC experiments they refuted an automatic response priming account driven by the irrelevant stimulus code. Instead, they inferred that congruency effects at the stimulus level could explain effects of irrelevant spatial SRC. However, this vision was rebutted by De Jong, Liang, and Lauber (1994) on the basis of distributional analyses and event-related brain potentials. More specifically, their results showed that correspondence effects within a spatial S-R processing context consist of two qualitatively different components, both represented in their dual-route model. That is to say, following the dual-route model two routes are activated upon the onset of the stimulus display. One unconditional route projects fast and automatically from the stimulus to the response independent of the primary task. Another conditional route is under voluntary control and reflects task-defined transformations from stimulus information to spatial response codes. If both the conditional and unconditional route point to the same response this will speed up performance. If, on the other hand, both routes project to a different response, it takes time to resolve this conflict and hence the overall response time will be slower (De Jong et al., 1994). To illustrate this, one could think of the Simon effect in which the irrelevant position is automatically and rapidly transformed into its corresponding spatial response. If this response is in concordance with the response that is initiated by the relevant stimulus information this al-

lows for a quick response. If however both activated response codes are in conflict with each other this will hamper performance because the response code associated with the irrelevant stimulus part needs to be inhibited.

1.3 Precursors of the neural overlap hypothesis

Besides theories that use a coding or attention perspective to account for compatibility and interference effects, some models in the history of experimental psychology started from the more adventurous neurobiological assumption that interference and compatibility are tightly linked with the cortical relation of the tasks or attributes involved. Early adopters of this vision were Kinsbourne and Hicks (1978) who proposed a model of *functional cerebral space*. This model tried to account for the limited performance encountered when doing a dual task by explicitly referring to the cerebral localization of the control centers called upon. More specifically, they assumed that simultaneous active cognitive programs can influence each other through spread of activation and the magnitude of this mutual influence depends on the functional and cortical distance between the loci where both programs are processed. The closer the processing loci are the more they will influence each other. Furthermore, Kinsbourne and Hicks (1978) assumed that the way programs influence each other depends on their comparability. If both programs are comparable, they will facilitate each other. If they are not comparable however, they will interfere with each other. Moreover, according to this model, programs are considered “comparable” not only when they utilize identical patterns of muscular contraction, but also when these patterns are conceptually similar. For instance, programs used for tapping a pattern with the hand and foot are considered to be comparable only if the rhythm tapped is the same, although the muscular contractions associated with each

movement are different.

At first sight, the proposition that distant comparable programs will facilitate each other more than distant ones seems rather vague. However, Kinsbourne and Hicks (1978) provided some examples to support this idea. For instance, they argued that controlling different responses with one hand and the opposite sided foot (controlled by different hemispheres) results in less interference compared to when using the foot and hand at the same side of the body, which are controlled by the same hemisphere (e.g. Briggs & Kinsbourne, 1978). Of course, most attempts to explore the concept of functional cerebral space employed the hemispheres as units of functional proximity. This means that in the examples they provided, programs were considered to be close when they were situated in the same hemisphere, while distant programs resided in opposite hemispheres.

One decade later, Posner, Sandson, Dhawan, and Shulman (1989) elaborated on the idea that performance of cognitive operations is governed by cortical and functional distance. They did so to study if the attentional system involved in a shadowing task is a unitary system subserving a variety of tasks, or if this type of attention is part of a fractioned attention system of which each component operates in different tasks.

To make predictions about the conditions under which repeating back (shadowing) auditory words would interfere with common visual priming tasks like spatial cueing or visual word priming, they used localization data acquired earlier in positron emission tomography (PET) studies of visual and auditory word processing (Petersen, Fox, Posner, Mintun, & Raichle, 1988; Posner, Petersen, Fox, & Raichle, 1988). They predicted and ultimately found that the shadowing task interferes with shifts of visual attention induced by the direction of a peripheral cue. At the neuro-anatomical level it is known from the PET studies that both require common attentional operations localized in the medial frontal lobe. On the other hand, shadowing did

not interfere with operations involved in the priming of a visual word form, which relies on areas of the ventral occipital lobe not involved during shadowing. Finally, both shadowing and semantic priming involve the anterior attention system and thus they found these to interfere.

The results were thus in favor of a commonly employed attention system. But more important for our case however was that their strategy proved was fruitful. The use of existing localization data made it possible to make predictions about interference based on the principle of cortical distance.

1.4 Scope of this thesis

I have now given a broad overview to reveal the context in which our research has been taken place. The aim of this thesis was to investigate the validity of the “neural overlap hypothesis” which is a neural-based account for irrelevant information processing. In Chapter 2, a study is presented that cannot be fully explained by the dimensional overlap model as defined by Kornblum et al. (1990). To be able to account for our results we suggested that besides dimensional overlap, neural overlap should also be taken into account. By neural overlap we mean functional and cortical relatedness of the processes involved in stimulus and response processing. Therefore the neural overlap hypothesis is conceived as the dimensional overlap model (Kornblum et al., 1990) extended by principles used in the functional cerebral space model of Kinsbourne and Hicks (1978).

To study neural overlap effects, a similar strategy will be employed as the one used in Posner et al. (1989). First, we will consequently review the literature in search for two sets of tasks or attributes. One set of irrelevant attributes that relies on similar neural processing regions as the relevant task and another irrelevant set that does not show this kind of neural overlap. Moreover, to define if sets of stimuli or tasks neurally overlap, we will always

make use of the relatively well known distinction between the ventral and dorsal processing pathway (e.g. Goodale & Milner, 1992; Milner & Goodale, 1995; Ungerleider & Mishkin, 1982). If the selected attributes are both processed within the same pathway (dorsal or ventral), they are considered to overlap at the neural level, whereas tasks and attributes that are not processed within the same pathway are considered not to overlap neurally.

Chapter 2

Effects of irrelevant digits on the relevant task depending on the overlap of neural circuits¹

¹This chapter is partly based on and adapted from Fias, Lauwereyns, and Lammertyn (2001) published in *Cognitive Brain Research*, Volume 12 and Lammertyn, Fias, and Lauwereyns (2002), published in *Cortex*, Volume 38

2.1 Part I — The origin of the neural overlap hypothesis

Efficient behaviour requires selection of information. In the domain of vision, the information acting upon our retinas is too abundant to be processed all to the same degree during the conversion of sensory input into goal-oriented behavioural output. Attentional mechanisms provide a means to give privilege to a subset of the available information (LaBerge, 1995; Van der heijden, 1992). Selection can be accomplished on the basis of a particular area in space (Jonides, 1981; Posner, 1980), a certain object (Duncan, 1984; Vecera & Farah, 1994; Yantis, 1992) or a particular visual feature (Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1990, 1991; Lauwereyns et al., 2000). In this paper we focus on feature-based attention.

Single-unit studies (McAdams & Maunsell, 2000; Treue & Trujillo, 1999) and functional imaging studies (Chawla, Rees, & Friston, 1999; Corbetta et al., 1990, 1991; Pinsk, Kastner, Desimone, & Ungerleider, 2000) indicate that feature-based attention modulates visual processing in specific areas of neocortex depending on which feature is being attended. Thus, feature-based attention operates as a localized neural adaptation to the task at hand. In line with this view, it is possible that the quality of feature-based selection depends on the extent to which relevant and irrelevant information are active in the same neural structures. That is to say, interference from irrelevant information on feature-based attention would be stronger if the relevant and the irrelevant feature are processed by the same neural structures than if both features pass through different neural structures.

To test this hypothesis, we devised a behavioural paradigm in which we varied the relevant information while keeping irrelevant information constant. As irrelevant information we used digits. Functional imaging (e.g. Chochon, Cohen, Moortele, & Dehaene, 1999; Pesenti, Thioux, Seron, & De Volder,

2000), electrode recordings (Abdullaev & Melnichuk, 1996) and patient studies (e.g. Dehaene & Cohen, 1995) convergently demonstrate the involvement of superior and inferior parietal areas in the semantic processing of the numerical magnitude of digits. The pre-semantic physical identity of digits is processed in inferior extrastriate cortical areas (Allison, McCarthy, Nobre, Puce, & Belger, 1994; Pesenti et al., 2000). Behavioral studies suggest that magnitude-related information is autonomously activated, as witnessed by effects of number magnitude on processing times in tasks for which a mere visual analysis of the digit suffices (Dehaene & Akhavein, 1995). As relevant information we used either contour-based 2D shape, color, or orientation. These features are processed to a different degree by parietal areas. Parietal involvement in the processing of shape and color is very restricted, whereas it is more extensive in the case of orientation processing (Eacott & Gaffan, 1991; Faillenot, Sunaert, Van Hecke, & Orban, 2001; Faillenot et al., 2001; Fias et al., 2000; Murata, Gallese, Luppino, Kaseda, & Sakata, 2000; Shikata et al., 2001; Taira, Kawashima, Inoue, & Fukuda, 1998; Walsh & Butler, 1996), not only in visually-guided motor tasks (Milner & Goodale, 1995; Murata et al., 2000) but also in associative visuo-motor transformation tasks like the two-choice manual response task adopted here (Faillenot et al., 2001; Fias et al., 2000; Shikata et al., 2001; Taira et al., 1998). Accordingly, we expected that semantic interference from number would be observed with attention to orientation, but not or to a lesser degree with attention to color or shape.

Semantic processing of digits can be evaluated in a binary manual response task. Dehaene, Bossini, and Giraux (1993) first showed an association between numerical value and the side of the response and labeled this effect the SNARC effect (spatial numerical association of response codes). Participants were asked to press one of two keys in response to an even number and the other key to an odd number. Smaller numbers were responded to faster with the left hand than with the right hand. The reverse happened for

larger numbers. Additional control experiments confirmed that the SNARC effect originates from accessing a numbers semantic magnitude representation, which is conceived of as a position on a left-to-right oriented mental number line (Brysbaert, 1995; Dehaene et al., 1993) such that there is congruity between small numbers and left-hand responses and between large numbers and right-hand responses. Therefore, we used the SNARC effect as a marker for semantic access. By having subjects direct attention away from the digit and asking them to perform a two-choice manual response task, we can evaluate the extent to which the unattended digit is processed as a function of the kind of processing being performed attentively.

2.1.1 Experiments 1–5

Materials & methods

Participants Sixty-eight Dutch-speaking subjects participated in the study. All participants had normal or corrected vision, and reported to be neuropsychologically healthy. Experiments 1-2 and 3-4 were each tested on the same sample (each 24 participants), in which case the order of experiments was counterbalanced. Subsamples were composed comparably in terms of age (Experiments 1-2: 19.3; Experiments 3-4: 18.3; Experiment 5: 24.2), sex (number of male participants: Experiments 1-2: 7; Experiments 3-4: 4; Experiment 5: 11), handedness (number of right-handed participants: Experiments 1-2: 20; Experiments 3-4: 20; Experiment 5: 16) and education (all participants were students or recent graduates in psychology).

Stimuli The numbers used ranged from 0 to 9 (except for Experiment 5 which used numbers 1 to 9) and were presented centrally on a black background as Arabic digits in Borland C's simplex font (VGA card in graphics mode). The digit subtended an area of 18×38 mm. In the colour condition, the digit was coloured in standard red or green (Experiment 2) as standardly

defined in Borland C's library, or lightcyan and cyan (Experiment 3). In all other experiments, the digits were presented in white with a visual stimulus superimposed in the centre. In Experiment 1 this stimulus was a triangle pointing upward or downward (subtending 18×18 mm). In Experiment 4 an oriented line segment (18×1 mm) was superimposed on the digit and in Experiment 5 a circle or a square (18×18 mm) was used.

Procedure Participants had to press one of two response keys, depending on the relevant feature (Experiment 1: triangle pointing upward or downward; Experiment 2: red or green; Experiment 3: light or dark cyan; Experiment 4: horizontal or vertical line; Experiment 5: circle or square). Key assignment was counterbalanced across participants. Before the actual experiment the participants took part in a training session, consisting of 20 trials with letters instead of numbers. In the training session an auditory feedback buzz was given when the participant pressed the wrong key. In the actual test session, each number was presented a fixed number of times (32 in Experiments 1, 2 and 5; 24 in Experiments 3 and 4): half of the times with the one relevant feature, the other half of the times with the other relevant feature. The whole set of trials was presented in randomized order with a different randomization for each subject.

Each trial started with the symbol “#” as fixation point ($18 \text{ mm} \times 50 \text{ mm}$) presented at the center of the screen for 1000 ms. The subjects were asked to fixate this point, but eye position was not monitored. Thereafter, the screen was erased and immediately followed by the stimulus. The stimulus remained on until a response was made, which was registered to the nearest millisecond from stimulus onset. A blank screen followed for 500 ms, after which the next trial started. The response box was connected to a PC-compatible Pentium and was placed at a comfortable position in front of the subject. The two response buttons were separated by ~ 30 cm. The eyescreen distance was plus

or minus 70 cm. Both speed and accuracy were stressed in the instructions, and the interval of numbers used was explicitly mentioned.

Data-analysis Trials with an RT shorter than 150 ms or longer than 1000 ms were discarded from all analyses. The cut-off value of 1000 ms fell well outside the grand average plus three standard deviations. This way, less than 1.5% of the data are excluded.

The presence of a SNARC effect was evaluated by means of a regression analysis of repeated measures data as described by Lorch and Meyers (1990). The advantages of using this method are reported elsewhere (Fias, Brysbaert, Geypens, & d'Ydewalle, 1996). In a first step, for each subject the median RT of the correct responses was computed for each number, separately for left and right responses. On the basis of these medians, differences in RT (dRTs) were computed by subtracting the median RT for the left hand from the median RT for the right hand. If there is an association between response side and number magnitude, we expect a negative correlation between number magnitude and dRT: relatively small numbers should elicit faster left responses, resulting in positive dRTs, whereas relatively large numbers should elicit faster right responses, and thus negative dRTs. Therefore, in a second step, a regression equation was computed per subject with number magnitude as predictor variable. In a third step t-tests were performed to test whether the regression weights of the group deviated significantly from zero. Since only a negative slope is expected theoretically, all reported p-values are one-tailed.

Results & discussion

Experiment 1: orientation, triangle pointing upwards or downwards Participants had to determine the orientation of a triangle superimposed on a digit (ranging from 0 to 9). Participants had to indicate whether

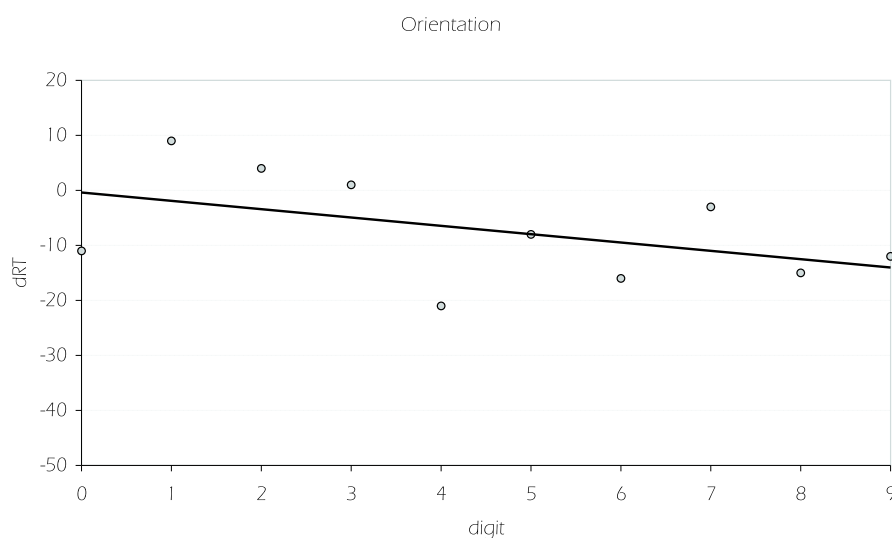


Figure 2.1: Experiment 1, differences in RT (dRT) between right and left hand responses (right minus left) as a function of the irrelevant digit in orientation discrimination (triangle pointing up or down). Circles indicate the observed dRTs. The continuous line depicts the predicted dRTs on the basis of the regression analysis.

the triangle was pointing upwards or downwards. A triangle was chosen as task relevant feature because it is perceptually salient and can be easily segregated from the digit background, in terms of Gestalt laws on the basis of good continuation and closure. Lesions of inferior parietal cortex have been shown to impair the discrimination of rotated shapes in the monkey (Eacott & Gaffan, 1991; Walsh & Butler, 1996). Single-cell recordings reported orientation selective cells in the anterior intraparietal area (Murata et al., 2000). Functional brain imaging demonstrated the involvement of parietal areas in the processing of spatial features like orientation (Faillenot, Decety, & Jeannerod, 1999; Faillenot et al., 2001; Fias et al., 2000; Shikata et al., 2001; Taira et al., 1998). Error rate averaged over subjects was 3.0% (with a maximum of 6.1%). There was no speed-accuracy trade-off, as indicated

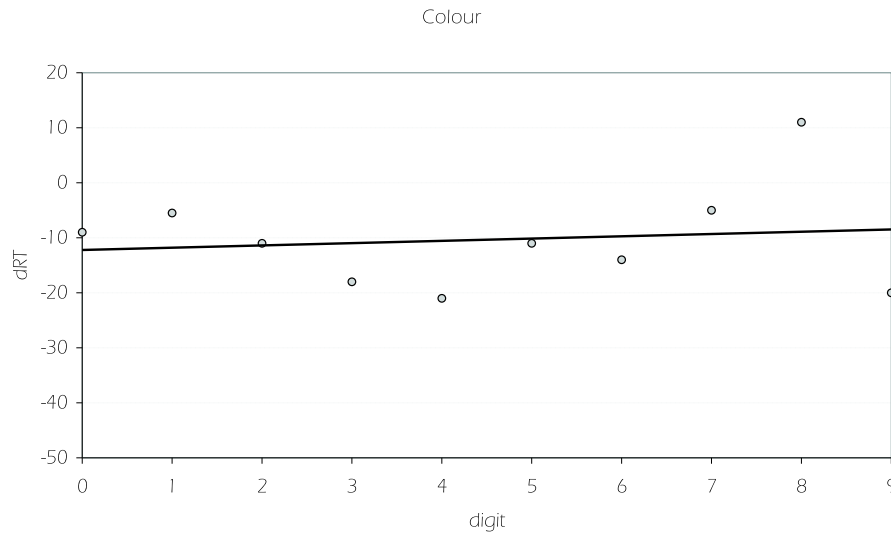


Figure 2.2: Experiment 2, differences in RT (dRT) between right and left hand responses (right minus left) as a function of the irrelevant digit in colour discrimination (red or green). Circles indicate the observed dRTs. The continuous line depicts the predicted dRTs on the basis of the regression analysis.

by the absence of a negative correlation between RT and number of errors, computed over 20 data couples (10 numbers, separated for left and right responses), $r(18) = +0.30$, $p < .30$. Mean RTs of correct responses with the digits 0 to 9 as irrelevant information were, respectively, 453, 452, 457, 467, 468, 465, 454, 455, 445 and 460 ms. The regression analysis of repeated measures data revealed the following equation (presented in Figure 2.1):

$$dRT = -0.27 - 2.03 \times \text{magnitude}$$

The significant contribution of number magnitude to the pattern of left hand - right hand differences ($t(23) = -2.91$, $SD = 3.4$, $p < 0.005$) reflects a reliable SNARC effect (with a negative slope observed in 17 participants) and shows that the unattended digits were processed semantically. As Brysbaert (1995) has argued, the semantic coding of the number zero

might be different than the semantic coding of other numbers. To make sure that this cannot bias our results, we also provide regression equations computed on the numbers 1 to 9. This reveals a nearly identical result: $dRT = -0.22 - 2.03 \times \text{magnitude}$ ($t(23) = -2.03, p < 0.05$).

The fact that there is a majority of negative dRTs does not obstruct the acceptance of a SNARC effect as it is highly likely that this is a result of the fact that a large majority of the participants was right-handed, resulting in overall faster right-hand responses. The SNARC effect shows how this right-hand advantage is modulated by the magnitude of the presented number.

Experiment 2: colour, red or green In Experiment 2 the relevant feature was changed to colour. As our parietal cortex is not involved in the processing of colour (Chao & Martin, 1999; Zeki, 1993) but relies primarily on structures in the ventral stream, less interference from the irrelevant digits is expected if participants respond to colour as the relevant feature. In fact, luminance was not controlled. For the present purposes, however, the difference between colour and luminance is unimportant as the neural correlates of attentive selection for colour and luminance have been shown to be essentially the same (Motter, 1994).

Error rate averaged over subjects was 2.5% (with a maximum of 7.7%). There was no speed-accuracy trade-off, as indicated by the absence of a negative correlation between RT and number of errors, computed over 20 data couples (10 numbers, separated for left and right responses), $r(18) = -0.02$; $p < 1$. Mean RTs of correct responses with the digits 0 to 9 were, respectively, 385, 386, 385, 388, 387, 376, 375, 386, 378 and 380 ms. The following equation was obtained and is presented in Figure 2.2:

$$dRT = -12.8 + 0.5 \times \text{magnitude}$$

Magnitude was not reliably different from zero ($t(23) = 0.44$; $SD = 6$, $p < 0.3$, with a negative slope in 10 participants). Omission of zero from

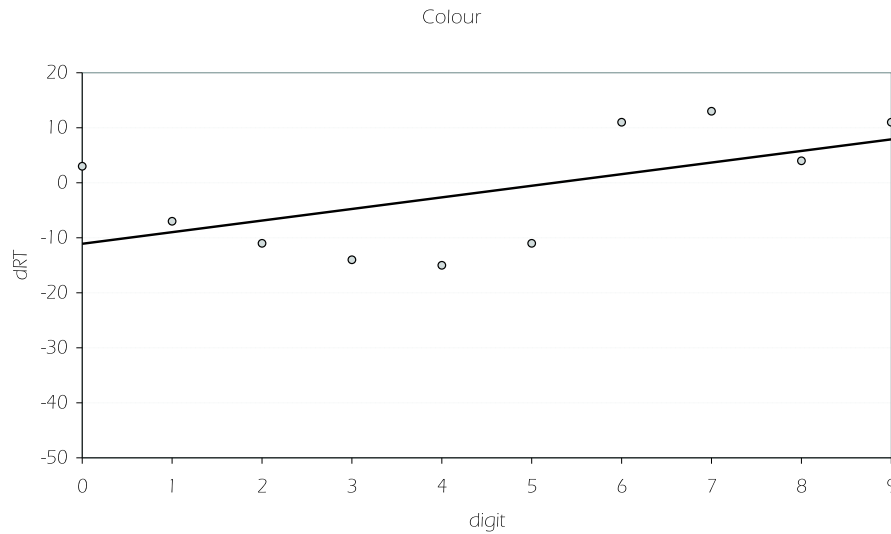


Figure 2.3: Experiment 3, differences in RT (dRT) of right and left hand responses (right minus left) as a function of the irrelevant digit in colour discrimination (light cyan or dark cyan). Circles indicate the observed dRTs. The continuous line depicts the predicted dRTs on the basis of the regression analysis.

the regression analyses reveals a similar equation: $dRT = -14.3 + 0.78 \times \text{magnitude}$ ($t(23) = 0.6$; $p < 0.25$). The direct comparison of the magnitude slopes in Experiments 1 and 2 revealed a reliably more negative slope in the orientation task than in the colour task ($t(23) = -1.86$; $p < 0.05$). Thus, whereas a reliable SNARC effect was obtained when orientation was the relevant feature, the SNARC effect completely disappeared when subjects attended to colour.

Experiment 3: colour, light cyan and dark cyan Average RTs in the colour condition of Experiment 1 were considerably shorter than in the orientation task. Possibly, latencies were simply too short for the number semantic system to become sufficiently activated to affect performance in the colour task. In order to evaluate this alternative interpretation, a new

colour/luminance discrimination experiment was carried out, using less discriminable colours/luminances (light and dark cyan).

Error rate averaged over subjects was 4.5% (with a maximum of 12.9%). There was no speed-accuracy trade-off, as indicated by the absence of a negative correlation between RT and number of errors, computed over 20 data couples (10 numbers, separated for left and right responses), $r(18) = 0.47$; $p < 0.05$. Mean RTs of correct responses with the digits 0 to 9 were, respectively, 499, 513, 505, 492, 494, 492, 481, 500, 489 and 489 ms.

Even when the colours were chosen such that the average latency was raised considerably (from 382 to 492 ms) up to a level at which a SNARC effect was obtained in Experiment 1 (457 ms), there was no indication of an effect of semantic processing of the digit. The following equation was obtained and is presented in Figure 2.3:

$$dRT = -8.31 + 1.95 \times \text{magnitude}$$

Magnitude tended to be positive, the reverse of the SNARC effect, but was not reliably different from zero ($t(23) = 1.5$; $SD = 6.8$; $p < 0.1$, with eight participants exhibiting a negative slope). The same was true for the regressions computed with zero excluded: $dRT = -12.45 + 2.8 \times \text{magnitude}$ ($t(23) = 1.58$; $p < 0.1$). Inspection of the dRTs for the individual numbers suggests a categorical effect of number magnitude. It has been shown that when precise numerical magnitude is irrelevant to the task, a stimulus can automatically be classified as small or large without coding the precise numerical value (Tzelgov, Meyer, & Henik, 1992). This crude small-large classification has been argued to be essentially different from refined numerical coding (Girelli, Lucangeli, & Butterworth, 2000; Tzelgov et al., 1992). Further research is needed to test whether the tendency observed here is a systematic effect and, if so, to explain why crude magnitude information is associated with spatial coordinates of response codes, opposite to refined numerical magnitude.

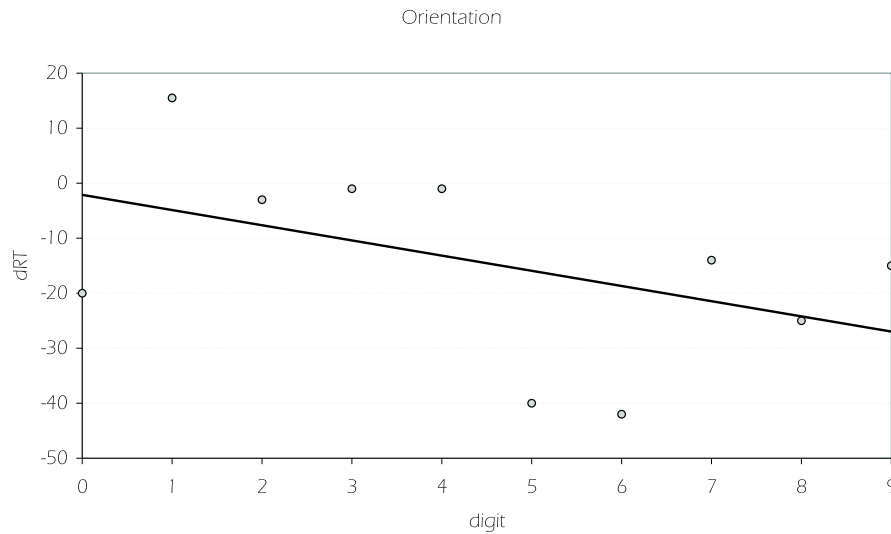


Figure 2.4: Experiment 4, differences in RT (dRT) between right and left hand responses (right minus left) as a function of the irrelevant digit in orientation discrimination (horizontal and vertical line). Circles indicate the observed dRTs. The continuous line depicts the predicted dRTs on the basis of the regression analysis.

Experiment 4: orientation, horizontal or vertical line segment To enable a direct comparison of the results of Experiment 3 with the same set of participants, the participants of Experiment 3 were subjected to an orientation task with lines instead of triangles. The line could be either vertical or horizontal. An oriented line rather than a triangle was used as a target to evaluate generality.

Technical failure caused data loss for one participant. Error rate averaged over subjects was 3.5% (with a maximum of 13.3%). There was no speed-accuracy trade-off, as indicated by the absence of a negative correlation between RT and number of errors, computed over 20 data couples (10 numbers, separated for left and right responses), $r(18) = 0.16$; $p < 1$. Mean RTs of correct responses with the digits 0 to 9 were, respectively, 468, 491,

479, 475, 509, 471, 468, 485, 466 and 476 ms.

Regression equations were computed in order to test for the presence of a SNARC effect. The following equation was obtained and is presented in Figure 2.4:

$$dRT = -1.48 - 3.74 \times \textit{magnitude}$$

Number magnitude was reliably activated, as witnessed by a significant SNARC effect ($t(22) = -3.59$; $SD = 5.0$; $p < 0.001$ with a negative slope in 18 participants). Without zero, the equation was $dRT = 13.0 - 5.13 \times \textit{magnitude}$ ($t(22) = -3.67$; $p < 0.001$). The direct comparison of the magnitude slopes from experiments 3 and 4 reveals a reliably more negative slope in the line orientation experiment ($t(22) = -3.27$; $p < 0.01$), whereas RTs between the two tasks did not differ ($t(22) = 0.76$; $p < 1$).

Experiment 5: shape, circle or square So far, the SNARC effect was present in those situations where a figure (triangle or line) had to be separated from the background. No figure-ground segregation was required in the colour experiments. To judge the possibility that the SNARC effect results from this figure-ground segregation process rather than from the overlapping parietal neural structures between orientation and digit processing, the following experiment was set up. A figure was superimposed on the digit background, but in a situation where the task does not use parietal processing resources. Participants had to discriminate between a circle and a square. Shape discrimination has repeatedly been shown to rely on IT in the ventral stream (Desimone & Allbright, 1984; Gross, Schiller, Wells, & Gerstein, 1967; Tanaka, 1996).

Subjects made an average of 3.9% errors, with a maximum of 15.3% errors made by one subject. No speed-accuracy trade-off was present, as indicated by the absence of a negative correlation between RT and number of errors,

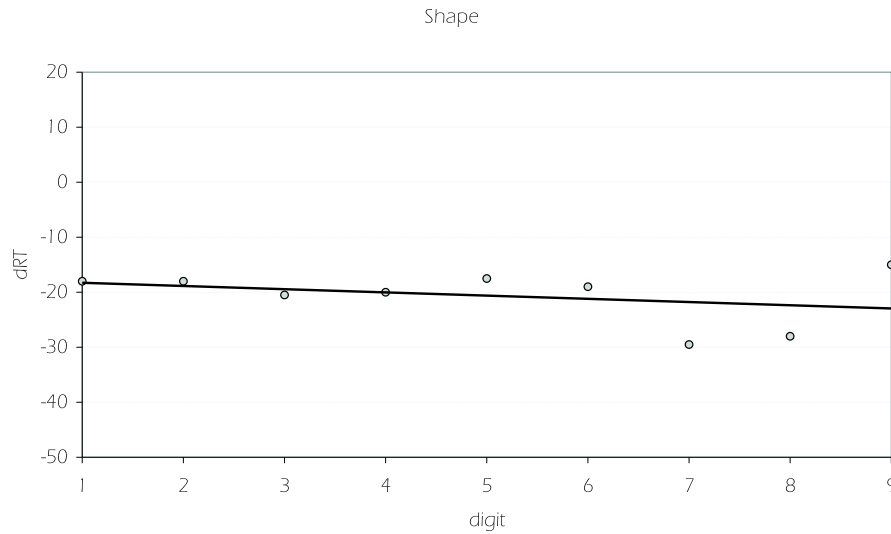


Figure 2.5: Experiment 5, differences in RT (dRT) between right and left hand responses (right minus left) as a function of the irrelevant digit in shape discrimination (circle or square). Circles indicate the observed dRTs. The continuous line depicts the predicted dRTs on the basis of the regression analysis.

computed over 18 data couples (nine numbers, separated for left and right responses), $r(16) = -.06$; $p < .40$. Mean RTs of correct responses with the digits 1 to 9 were, respectively, 447, 458, 461, 462, 464, 466, 449, 459 and 495 ms. The regression analysis of repeated measures data resulted in the following equation (shown in Figure 2.5):

$$dRT = -18 - 0.36 \times \text{magnitude}$$

No SNARC effect was found as there was no significant contribution of number magnitude to the pattern of right hand minus left hand differences ($t(19) = -.35$, $SD = 4.5$, $p < 0.3$; six participants with a negative slope). This shows that the unattended digits were not processed up to the level of semantic information.

2.1.2 Experiment 6: same stimuli, different task

Together, all previous behavioural experiments provided evidence that the efficiency of feature-based attention critically depends on the degree of overlap of neural structures recruited by distractor and target. However, one potential problem with this series of experiments needs to be eliminated before the degree of neural overlap can be taken as a strong account of the observed pattern of results. Up until now, the stimuli were different from experiment to experiment. In the orientation and shape experiments the target was superimposed on the digit distractor and both target and distractor were presented in white. To the contrary, in the colour experiments nothing was superimposed on the digits and the digit was presented in two possible colours. In order to exclude the difference in stimulation and its possible interactions with attention as a possible reason for the observed pattern of results, we kept all stimulus material constant for all conditions in the present experiment, while only varying the task. Stimuli now consisted of digits ranging from 1 to 9, either presented in cyan or light cyan and rotated to the left or presented upright. This resulted in two conditions, one where participants had to attend to the colour of the stimulus, and a second where responses had to be made to the orientation of the digit.

Materials & method

Participants Twenty Dutch-speaking subjects (17 female) participated in the experiment. All participants had normal or corrected to normal vision, and reported to be neuropsychologically healthy. All participants were psychology students.

Stimuli The numbers used ranged from 1 to 9 and were presented centrally on a black background as Arabic digits in Arial font. The size of the digit approximately extended 1.3° vertically and 0.9° horizontally. The colour of the

digits could be a light shade of cyan (RGB: 0;52;52), or a darker shade of cyan (RGB: 0;37;37). Furthermore, the digits could be presented upright or tilted 10 degrees to the right.

Procedure To give a response, participants had to press one of two response keys, depending on the relevant feature. All participants completed four blocks, two where colour was the task-relevant feature (colour condition) and two for which orientation was the task-relevant feature (orientation condition). Within every condition, participants did two blocks and key-response assignment was reversed between these blocks. Block-order was counterbalanced over participants.

Before the actual experiment, all participants went through a training session, consisting of 20 trials with letters instead of digits. During this training, feedback was given upon erroneous response. For the actual test session, each block consisted of 108 trials. Each digit (1–9) in each possible combination of colour and orientation was presented three times. All trials started with a plus-sign as a fixation point ($0.8^\circ \times 0.8^\circ$) presented in the centre of the screen for 1000 ms. Thereafter, the screen was blanked and the stimulus appeared immediately. The stimulus remained on-screen until a response was made, which was registered to the nearest millisecond from stimulus onset. After a response was given, a blank screen appeared for 500 ms, after which the next trial began. The response modalities were identical from the previous five experiments. Both speed and accuracy were stressed and the interval of numbers used was explicitly mentioned.

Results & discussion

Error rate averaged over subjects was 4.9% for the colour condition and 4.7% for the orientation condition (with a maximum of 11.4% and 12.5% respectively). There was no speed-accuracy trade-off as indicated by the

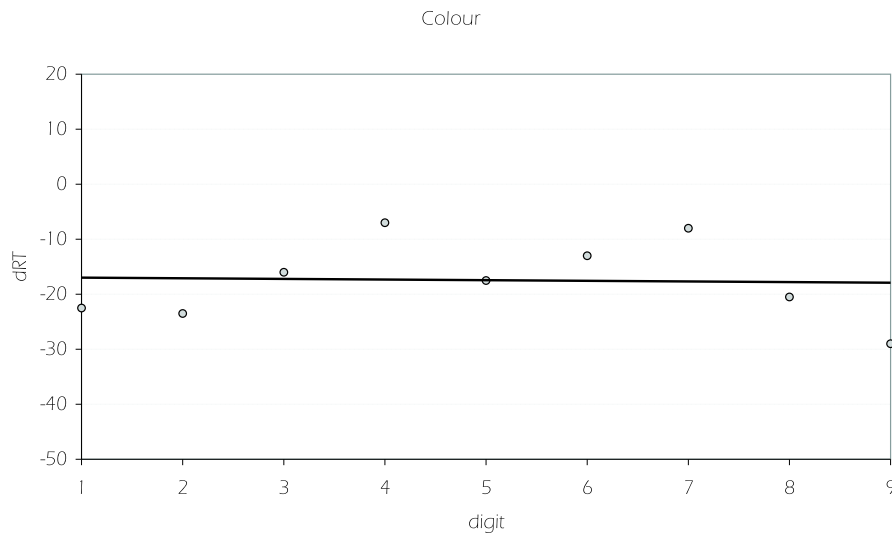


Figure 2.6: Differences in RT (dRT) between right and left hand responses (right minus left) as a function of the irrelevant digit for the colour condition. Circles indicate the observed dRTs. The continuous line depicts the predicted dRTs on the basis of the regression analysis.

absence of negative correlation between RT and number of errors, computed over 18 data couples (9 numbers, separated for left and right responses), $r(16) = +.38$; n.s. (colour condition) and $r(16) = +.72$; $p < .001$ (orientation condition). Mean RTs of correct responses for the numbers 1 to 9 were respectively 590, 566, 572, 557, 555, 560, 573, 556 and 565 ms for the colour condition and 561, 538, 632, 549, 572, 599, 554, 592 and 588 ms for the orientation condition.

The regression analysis of repeated measures data led to the following equations (presented in Figure 2.6 and Figure 2.7):

$$\begin{aligned} \text{colour: } dRT &= 17.05 - 0.13 \times \text{magnitude} \\ \text{orientation } dRT &= 11.59 - 2.56 \times \text{magnitude} \end{aligned}$$

For the colour condition, the slope did not differ significantly from zero ($t(19) = .137$; n.s.), which means that the digits were not processed up

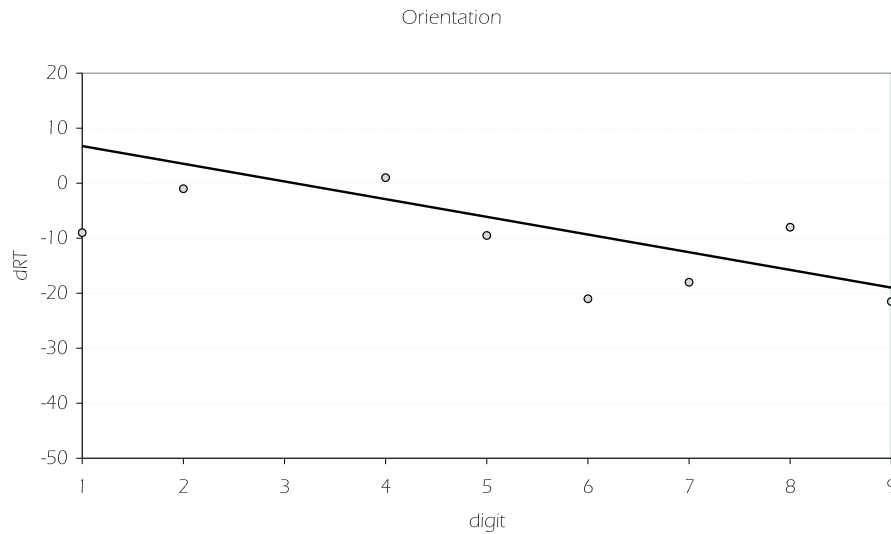


Figure 2.7: Differences in RT (dRT) between right and left hand responses (right minus left) as a function of the irrelevant digit in the orientation condition. Circles indicate the observed dRTs. The continuous line depicts the predicted dRTs on the basis of the regression analysis.

to the semantic level. With regard to the orientation condition, number magnitude was reliably activated as witnessed by a significant SNARC effect ($t(19) = 2.47$; $p < 0.01$).

In sum, we found that the task-irrelevant digits were processed semantically (as indicated by the SNARC effect) in the orientation condition but not in the colour condition. Average reaction times were the same in both conditions such that dependency of the SNARC effect on elapsed processing time can be ruled out. This pattern of results excludes unequal stimulation as an account for the data obtained in earlier experiments and provides further support for the hypothesis that the overlap between neural structures involved in the processing of relevant and irrelevant information is a determinant of the efficiency of feature-based selective attention. Digits are processed semantically in parietal cortex and if the processing of the relevant

feature is also processed within the parietal cortex (as is the case for orientation), an effect on response times was obtained from the digits magnitude. There was no effect however, from the irrelevant digit on the processing of colour, which relies only minimally on parietal resources. This observation is in line with the view that feature-based attention modulates processing in feature-specific cortical areas by enhancing their neural activity.

2.1.3 Discussion

In a series of experiments we showed that interference from irrelevant information on feature-based attention is stronger if the relevant feature is processed by the same neural structures as the irrelevant feature. Irrelevant information was the same in all experiments and consisted of digits. Digits are processed semantically in the parietal cortex (Chochon et al., 1999; Pesenti et al., 2000). When processing of the relevant feature depended on parietal cortex, as is the case for orientation processing (Experiments 1, 4 and 6), there was an effect of the digit's magnitude on response times. Conversely, there was no effect of the irrelevant digit on the processing of colour (Experiments 2, 3 and 6) or shape (Experiment 5), which relies only minimally on parietal resources.

Importantly, alternative accounts can be ruled out. Firstly, there was no dependency of the effect on elapsed processing times. In Experiments 3 and 5 conditions were created such that no SNARC effect was observed with similar or even longer response times than those observed in conditions which elicited a reliable SNARC effect (Experiment 1). Furthermore, the RT levels for the colour and orientation condition of Experiment 6 were not different but showed the same pattern of SNARC effects just the same. Secondly, in contrast with Humphreys and Boucart (1997), mechanisms involved in object-based attention cannot account for the pattern of semantic influences in our experiments, with number as irrelevant information. In-

deed, the SNARC effect did not depend on whether the relevant information consisted of a 2D object. With a 2D object as a target against the numerical background a SNARC effect was observed in an orientation identification task, but not in a shape discrimination task. Importantly, the 2D objects were of equal complexity in both tasks. Thirdly, there was no difference in dimensional overlap between the experiments (Kornblum et al., 1990; Zhang, Zhang, & Kornblum, 1999): neither the processing of colour, shape or orientation involves stimulus or response representations that are related to the numerical value represented by a digit. Fourth, a perceptual confound can also be ruled out because in Experiment 6, identical stimuli were employed for both the colour and orientation condition (only the task varied), but still there was only a SNARC-effect present for the orientation condition.

Having excluded alternative explanations, we can conclude that the efficiency of feature-based attention is determined by the neural structures that are involved in the processing of both relevant and irrelevant information. If the processing of target and distractor make use of (partly) shared neural circuits then feature-based attention is less efficient compared to the situation where the processing of target and distractor is mediated by distinct circuits. These observations are in line with the view that feature-based attention modulates processing in feature-specific cortical areas (Chawla et al., 1999; Corbetta et al., 1990, 1991; McAdams & Maunsell, 2000; Pinsk et al., 2000; Treue & Trujillo, 1999). Our results show that this relative enhancement is less efficient when there is neural overlap between target and distractor processing. Whether relative enhancement is accomplished by facilitation or by inhibition cannot be distinguished with the present paradigm.

Our current task —aimed at studying feature-based attention, naturally also implies a motor component: participants had to associate the visual information with either a left-hand or right-hand response. This type of task involves learning an arbitrary rule to convert visual information into

a motor command, as opposed to the more straightforward rules that underlie visually guided motor processing. Toni and Passingham (1999) have suggested that the former type of processing is regulated primarily by prefrontal cortex, whereas parietal cortex would be more involved in visually guided motor processing (Rushworth, Nixon, & Passingham, 1997). Thus, it may seem surprising at first that we find interference on parietal processing at all in our task with arbitrary visuo-motor associations. However, considering the fact that we kept the response dimension constant in all our experiments, it becomes clear that the SNARC effects must have emerged at a stage of information processing before motor control, that is, while encoding perceptual/cognitive representations. Representations of line orientation would compete with representations of number magnitude in parietal cortex. Consequently, the SNARC effect would already be implied in the neural code that prefrontal cortex receives from parietal cortex to compute the appropriate response. This leads us to the speculative assumption that stronger SNARC effects might be obtained if the response programming itself also takes place in parietal cortex, in a visually guided motor task. Before future research tests this hypothesis, however, we can already conclude from the present data that neural overlap between target and distractor processing in parietal cortex contaminates response times even in tasks with arbitrary stimulus-response association rules. With “neural overlap” we imply that the signal-to-noise ratio of the information coded by a neural unit, be it a single neuron or a cell assembly, can be directly affected by irrelevant afferents. For instance, the tuning curve of a neuron to a relevant feature (e.g. upward orientation) may be affected —flattened or even sharpened, depending on whether task-irrelevant input to the neuron coincides with the relevant input. Such influences would not occur if the irrelevant information uses a different neural pathway. This hypothesis borrows the concept of “overlap” from the dimensional-overlap theory (Kornblum et al., 1990; Zhang et al.,

1999), but suggests that similarity of neural circuits, rather than similarity of stimulus and/or response, is the basis of interference. In this sense, it is an extension of the dimensional-overlap theory: it predicts interference in all of the cases of dimensional overlap, but also in cases where dissimilar stimuli and/or responses are processed (at least in part) by the same neural structures.

Obviously, the present evidence from behavioural experiments can only indirectly support a hypothesis of neural overlap. We depend on the existing literature to identify neural circuits involved in discriminating colour, shape or orientation, and in autonomous number processing. Event-related functional imaging and/or single-unit study using the present or a similar paradigm is required to provide direct evidence for our neural-overlap hypothesis. Some preliminary evidence, however, does already exist with primate prefrontal neurons in visual discrimination tasks (Bichot & Schall, 1999; Lauwereyns et al., 2001). For instance, Bichot and Schall (1999) showed that neurons in the frontal eye field coding the saccade target based on one visual feature (e.g. a red colour) responded more clearly if the irrelevant feature (e.g. a square shape) indicated the previous saccade target than if it did not. In other words, an irrelevant stimulus-response association directly affects the signal-to-noise ratio of neurons whose code pertains to the same response dimension. Analogous processes of neural overlap in parietal cortex may account for our present data, with semantic influences from the number on feature processing in the dorsal pathway, but not in the ventral pathway.

Our results also speak to the issue of the automaticity in number processing. A number of studies support the claim that numerical processing automatically progresses to a stage of semantic access, on the basis of the robust occurrence of semantic effects under conditions that do not require semantic access for successful task completion (e.g. Dehaene & Akhavein, 1995). The results presented here confirm that automaticity is an important

characteristic of number processing, because we found a reliable indication of semantic number processing in the orientation condition despite the fact that the digits were completely irrelevant to the task. However, the observation that automatic semantic access depends on the type of relevant feature and neural structures involved, qualifies and modifies the concept of automaticity, in the sense that it is subject to conditions imposed by brain organization and function.

2.2 Part II — Ruling out alternative explanations

According to Kornblum et al. (1999) dimensional overlap is achieved when relevant and/or irrelevant stimulus sets are perceptually, conceptually, or structurally similar to each other and/or the response set in the task. All experiments presented in first part were designed to represent Type 3 ensembles with respect to the dimensional overlap taxonomy. This means that there was always and only dimensional overlap between the irrelevant stimulus dimension and the response dimension. As a result one would predict that, normally, the irrelevant information presented in all experiments is processed similarly irrespective of the relevant task at hand. Nevertheless, this was not the case: the irrelevant number was processed differently depending on the type of relevant task that had to be performed. In the previous part, strong semantic SNARC effects were found when an orientation task was used (Experiment 1 and 4), but this marker for the semantic processing of the irrelevant number was less pronounced in the colour and form experiments (Experiments 2, 3 and 5). For Experiment 6, similar results were obtained: responding to the orientation of coloured numbers resulted in larger SNARC effects compared to responding to the colour of oriented numbers.

To account for these remarkable data we introduced the neural overlap

hypothesis. This theory proposed that the differences found between orientation tasks on the one side and colour or shape tasks on the other side, originate at the level of the specific neural circuits involved in the processing of relevant and irrelevant information. This means that the stronger SNARC effects obtained in the orientation experiments are the result of the neuro-anatomical similarity between orientation processing and number processing, even though the relevant orientation attribute and the irrelevant number show no dimensional overlap within the visuo-spatial domain.

It is important to see that the neural overlap effect found in the first part of this chapter is a modulating effect and its impact on the response is indirect. Neural overlap between the relevant and irrelevant stimulus part does not affect the response directly, but makes that the irrelevant number representation reaches a higher level of activation compared to when there is no neural overlap between the relevant and irrelevant stimulus part. This higher activation level in turn resulted in a stronger SNARC effect. In other words, neural overlap affected the activation level of the irrelevant number representation, which in turn had an effect on the size of the SNARC effect. Therefore, it makes more sense to assume that neural overlap *modulates* the irrelevant S-R transition. The mechanisms underlying this modulation are straightforward. If neurally similar circuits process the relevant and irrelevant stimulus information, this will result in a less efficient inhibition of the irrelevant information, making it possible for this irrelevant information to be processed. If, however, neurologically distinct circuits process relevant and irrelevant stimulus information, inhibition of irrelevant will ensue, and hence the irrelevant stimulus part will not be semantically processed.

Before accepting the neural overlap theory as a valid explanation for the results obtained, some issues need further clarification. First, it is necessary to check if indirect associations between the relevant and irrelevant stimulus attributes, or else, the relevant stimulus attribute and the response can

alternatively explain the differences between orientation tasks and colour or shape tasks. With indirect associations we refer to relations between, for instance, the up-down dimension and left-right dimension. Second, it is also important to find out if the results are not due to attentional effects. Besides the fact that colour and orientation use different processing pathways, one could also argue that the colour task can be easily solved by focusing on a small portion of the stimulus, circumventing the necessity to process the whole stimulus and thus reducing or eliminating its semantic effects.

2.2.1 Indirect associations

In all the experiments conducted in the first part of this chapter, we refrained from investigating the possibility of indirect associations between the stimulus and response set. Consider for instance Experiment 1 where we used up or down pointing triangles superimposed on an irrelevant number. We did not check if the up-down dimension was related to the left-right dimension associated with the number and the response. At first sight there is no ground to believe that up and down pointing triangles (Experiment 1), vertical and horizontal oriented lines (Experiment 4) or the orientation status of a number (Experiment 6, orientation condition) dimensionally overlaps with the irrelevant number or the response. Weeks and Proctor (1990), however, showed that dimensional overlap is not always as straightforward as is generally believed. In this particular study Weeks and Proctor (1990) found that in some situations stimuli presented in the vertical dimension are associated with responses in the horizontal dimension. More specifically, they found that participants responded faster with “right” responses to stimuli presented “above”, while stimuli presented “below” are faster responded to with a “left” response. According to Weeks and Proctor (1990), this above-right/below-left advantage cannot be attributed to preferential motor effects (see Bauer & Miller, 1982), nor to hemispheric activation differences (see

Cotton, Tzeng, & Hardyck, 1980), but originates from the cognitive coding at the S-R translation stage. This shows that dimensional overlap is not restricted to similarities within one dimension, but can also be the result of orthogonal associations between the up-down and left-right dimension. It has to be noted though that Weeks and Proctor (1990) only considered spatial S-R compatibility effects between the *relevant* stimulus dimension and the response (Umiltá, 1991; Weeks & Proctor, 1991). However, in a recent study by Nishimura and Yokosawa (in press) participants responded with a left or right key press to the colour of a stimulus that was positioned above or below the fixation point. Even though stimulus position was irrelevant, they observed an above-right/below-left advantage. This shows that orthogonal S-R effects are not restricted to relevant S-R relations, but even apply to irrelevant S-R relations and this is referred to as an orthogonal Simon effect.

To account for orthogonal SRC effects (SRC effects between the up-down and left-right dimension), Weeks and Proctor (1990) proposed the *salient features coding* account. According to this account, stimuli and responses are coded asymmetrically onto their respective dimensions. In the vertical dimension “above” positions tend to be more salient than “below” positions resulting in a processing advantage for “above” positions (Chase & Clark, 1971; Seymour, 1974). In the horizontal dimension, right-handed people code right faster than left (Olson & Laxar, 1973, 1974). Converted to a polarity dimension, one could say that above and right are of positive polarity compared to down and left which are of negative polarity. In turn, this structural polarity assignment applies for both stimuli and responses, which eventually results in dimensional overlap effects of polarity. This means that “above” corresponds to “right” because both are positive, while “below” corresponds to “left” because they are negative.

With regard to our experiments, we want to assure that the stronger SNARC effect found in the orientation experiments was not the result of an

obfuscated orthogonal dimensional overlap effect between the relevant orientation attribute at one side and the irrelevant number or the response on the other side. The problem is that an above-right/left-down relation was only present in the orientation experiments and not in the control experiments which used colour or shape instead of orientation. This means that for the orientation conditions congruency could emerge at two levels. First, between the irrelevant number and the response (SNARC-congruency) and second, between the orientation of stimulus and the response (above-right/down-left advantage). For the colour experiments on the other hand, there was only one possible level of congruency, namely between the irrelevant number and the response (SNARC). This difference between both types of conditions may have enhanced the SNARC effect in the orientation conditions, instead of neural overlap like we assumed. To rule out this possibility, we conducted some additional analyses. All effects were analysed at the .05 significance level.

For Experiment 1 (triangles pointing up or down) we first checked if there was a preferential mapping between the orientation of the triangle (up or down) and the location of the response (left or right). Because each participant was instructed to use either an up-left/down-right mapping or alternatively an up-right/down-left mapping, we simply compared both groups. Statistically there was no difference between the groups (481 vs 473 ms, respectively and $t(22) = .39, p = .70$), which means that there is no preferred mapping of up or down pointing triangles to right or left responses. Besides this analysis of the irrelevant S-R relation, we also checked for an interaction at the stimulus level between the orientation of the triangle (up-down) and the spatial feature connoted with numbers (left-right²), but this was not the case. Mean RTs for up-right (473 ms), down-left (480 ms), up-left (478 ms)

²numbers smaller than 5 were coded as “left” and numbers larger than 4 were coded as “right”.

and down-right (479 ms) trials were not different from each other ($F < 1$).

Subsequently, we looked for similar effects in Experiment 4 (horizontal or vertical lines). Statistically, there was no difference in average reaction time between participants of both S-R mapping groups (vertical press right, horizontal press left, or vice versa). This suggests that there is no preferred association between the vertical-horizontal stimulus attributes and the left-right responses (the mean RT for the horizontal-right/vertical-left group was 477 ms versus 493 ms for the horizontal-left/vertical-right group, $t(18) = 1.36$, $p = .19$). Furthermore, there was no interaction between the relevant stimulus attribute (vertical-horizontal) and the irrelevant spatial number attribute. The average RTs for horizontal-left (484 ms), horizontal-right (485 ms), vertical-left (492 ms) and vertical-right (482 ms) did not differ from each other ($F < 1$).

Finally, the same set of analyses was conducted for Experiment 6. In this experiment, all participants performed both S-R mappings, and therefore an interaction between the orientation status of the number and the response-side would indicate the existence of an indirect association between both. However, this was not the case ($F(1, 21) = 2.82$, $p > .05$). Similarly, we looked for an interaction between the orientation of the number and its left or right connotation, but again, this interaction was not significant ($F < 1$). The average RTs were 519 ms for rotated small numbers, 531 ms for rotated larger number, 539 ms for upright presented small numbers and 545 ms for upright large numbers.

To summarize, the neural overlap hypothesis still holds. Our scrutiny did not reveal indirect association effects comparable to the up-left/right-down advantage found by for instance Weeks and Proctor (1990) or Nishimura and Yokosawa (in press).

2.2.2 Different pathways or global dominance?

A second point needing further clarification is whether our results can solely be explained in terms of different processing pathways, or if they can alternatively be explained by the use of global versus local attention strategies. This question is important because the majority of our experiments that fail to reveal a SNARC effect were based on a colour-discrimination task (except for one shape experiment), which in principle does not require global processing of the stimulus.

This topic is closely related to an issue investigated in a series of studies by Boucart and Humphreys (1992, 1994), Boucart, Humphreys, and Lorenceau (1995) and Humphreys and Boucart (1997). In these studies, participants first saw a reference picture that was quickly followed by a display containing two laterally presented pictures (the target and the distractor). The task of the participants was to select the side of the picture matching the reference. This involved the selection of a global (Boucart & Humphreys, 1992, 1994; Boucart et al., 1995) or a local (Humphreys & Boucart, 1997) part of the stimulus, and the matching task could be done on the basis of form-features (orientation, size, shape) or colour. The results of these studies revealed two main mechanisms, namely (a) global dominance and, (b) cross-dimensional inhibition. Global dominance refers to the fact that when participants attend global properties of objects (their overall size, orientation or shape) the semantic representations of these objects are automatically accessed. As a consequence, this results in semantic interference effects even when doing asemantic tasks like physical matching (Boucart & Humphreys, 1992, 1994). Global dominance is not restricted to tasks requiring to attend global properties though. In Humphreys and Boucart (1997, Experiment 1A and 1B), participants had to respond to the orientation of a line segment presented within the reference target and distractor pictures, making global processing unnecessary to solve the task. Nevertheless, effects of the semantic relations

between the stimuli appeared suggesting global processing.

Global dominance is not ubiquitous though. When Boucart and Humphreys (1994) used global colour instead of orientation as the to be attended feature, all semantic effects were eliminated. This finding was replicated by Humphreys and Boucart (1997) who used local colour instead. To explain these results, Humphreys and Boucart (1997) suggested that when it is possible to use colour information for responding, the form-processing pathway is inhibited, preventing the objects themselves to be processed semantically.

At first sight, the framework proposed by Humphreys and Boucart (1997) does not conflict with the neural overlap hypothesis. When the relevant line segments and the irrelevant pictures surrounding and accompanying these line segments both appeal to the form-pathway (e.g. Humphreys & Boucart, 1997, Experiment 1A), this is just the same as asserting that both relevant and irrelevant information show neural overlap. The result of this is that irrelevant information inhibition is difficult and therefore irrelevant information is processed.

The comparison with the neural overlap hypothesis also holds for the colour experiments presented in Boucart and Humphreys (1994) and Humphreys and Boucart (1997). For these experiments, there is probably less neural overlap between the relevant feature and the irrelevant information. The consequence of this is that the irrelevant form-pathway is inhibited efficiently, preventing the activation of their semantic representations.

However, there are some exceptions to the two main principles presented above. Boucart et al. (1995, Experiment 3) showed that when colour information is inextricably bound up with the global form of the irrelevant picture, semantic processing does take place. In this specific experiment, red and green coloured pixels were randomly distributed along the contours of the pictures with one of the colours being overrepresented, and participants had to match the dominant colour to the reference. The fact that in this

case form was processed was explained by suggesting that when colour is inherently coupled with form, activation of the form pathway is necessary to select the spatial area over which colour information is integrated, and hence the irrelevant objects are processed semantically.

Even though Boucart et al. (1995) showed that performing a colour task under some conditions will result in (irrelevant) form processing, the question remains if this would also apply for the stimuli used in the experiments presented earlier. Not in the least because there are some important differences between the procedure used in Boucart et al. (1995) and ours. For instance, the use of a display containing two pictures combined with the fact that the position of the target is (evidently) uncertain, promotes attention to be broad initially. As Navon (1977) pointed out, the attention window only focuses from global to local information over time, but nevertheless, there is a chance that global form is processed at the beginning of this operation. In our studies, both the relevant and irrelevant information were consequently presented in the centre of the screen, reducing the need for distributed attention. Of course, this does not exclude a broad attentional starting point, but at least the need to apply this mechanism is not promoted.

Another possible problem with the stimuli used in Boucart et al. (1995) is that semantic and physical similarity can be confounded (i.e. a dog and a cat look more alike than for instance a dog and a guitar), at least with some of the stimuli. In Humphreys and Boucart (1997) this problem was investigated, and even though extra analyses suggest that this cannot completely explain the semantic effects found in their matching task, the authors admitted that this might nevertheless have played some role. The fact that we did not use a matching task of course excluded this problem for our studies.

To rule out the possibility that the different processing of irrelevant numbers as we found earlier with orientation and colour tasks is due to distributed attention differences we did an additional experiment similar to the one em-

ployed in Boucart et al. (1995). More specifically we wanted to check if using a distributed colour task with irrelevant numbers also results in global form processing and hence semantic effects. According to the framework of Humphreys and Boucart (1997) the extended integration of colour with form will result in semantic effects from the irrelevant number. The neural overlap hypothesis on the other hand expects no semantic effects for the colour condition.

2.2.3 Experiment 7: distributed colour

The stimuli, method and procedure employed in this experiment are for the most part identical to the one used in Experiment 6. The only difference concerned the way in which colour was represented in the stimuli. For the present experiment, we used coherence stimuli. Only fifty percent of the number plane was filled with red and green coloured dots and the distribution of the different colours over this plane was chosen randomly and individually for each trial. Using this approach, people had to process the whole number, which guarantees that the absence of any effects cannot be attributed to a narrowed focus of attention.

Method

Participants Twenty-four English-speaking persons participated in this experiment (17 female; 21 right-handed). All participants were students at the Victoria University of Wellington and their mean age was 21.3 (the youngest participant was 18 and the oldest 46, $SD = 6.37$). They all had normal or corrected-to-normal vision and reported to be neuropsychologically healthy.

Stimuli All participants had to run through a sequence of two conditions: a colour condition and an orientation condition. In both conditions, the par-

ticipants saw Arabic digits ranging from 1 to 9 as stimuli, and these appeared in one of four possible orientation and colour configurations. Combined, this led to a total of 36 possible types of stimuli.

All Arabic numbers were presented upright or rotated ten degrees to the right. Furthermore, the numbers were presented in one of two possible colour profiles. The colour profiles were made like this: only fifty percent of the pixels forming the number were randomly filled with red or green coloured dots. The remaining fifty percent remained black, the colour of the background. From the coloured pixels, 60% was coloured in one colour and 40% in the other colour. All coloured pixels were randomly distributed over the plane constituting the number. It was the participant's task to respond to the dominant colour.

Procedure The procedure was identical to the Experiment 6, only the colour task differed slightly. Instead of responding to the colour of the stimuli, participants now had to respond to the dominant colour.

Results

Technical failure caused the loss of one participant's data. All trials wrongly responded to were removed from the analysis. On average participants made 5.6% errors ($SD = 3.4$). Furthermore, we applied a cut-off value based on the personal mean plus or minus 3 standard deviations which resulted in the removal of 7.9% of the remaining data. The average response speed for both conditions did not differ significantly ($F < 1$) with the mean reaction time for the colour condition being 552 ms ($SD = 19,88$) and 535 ms ($SD = 14,74$) for the orientation condition. Mean reaction times for the digits going from 1 to 9 were 552, 554, 550, 553, 552, 552, 562, 547 and 546 ms for the colour condition, and 534, 524, 546, 528, 529, 541, 531, 536 and 534 ms for the orientation condition. There was no speed-accuracy trade-off as both conditions

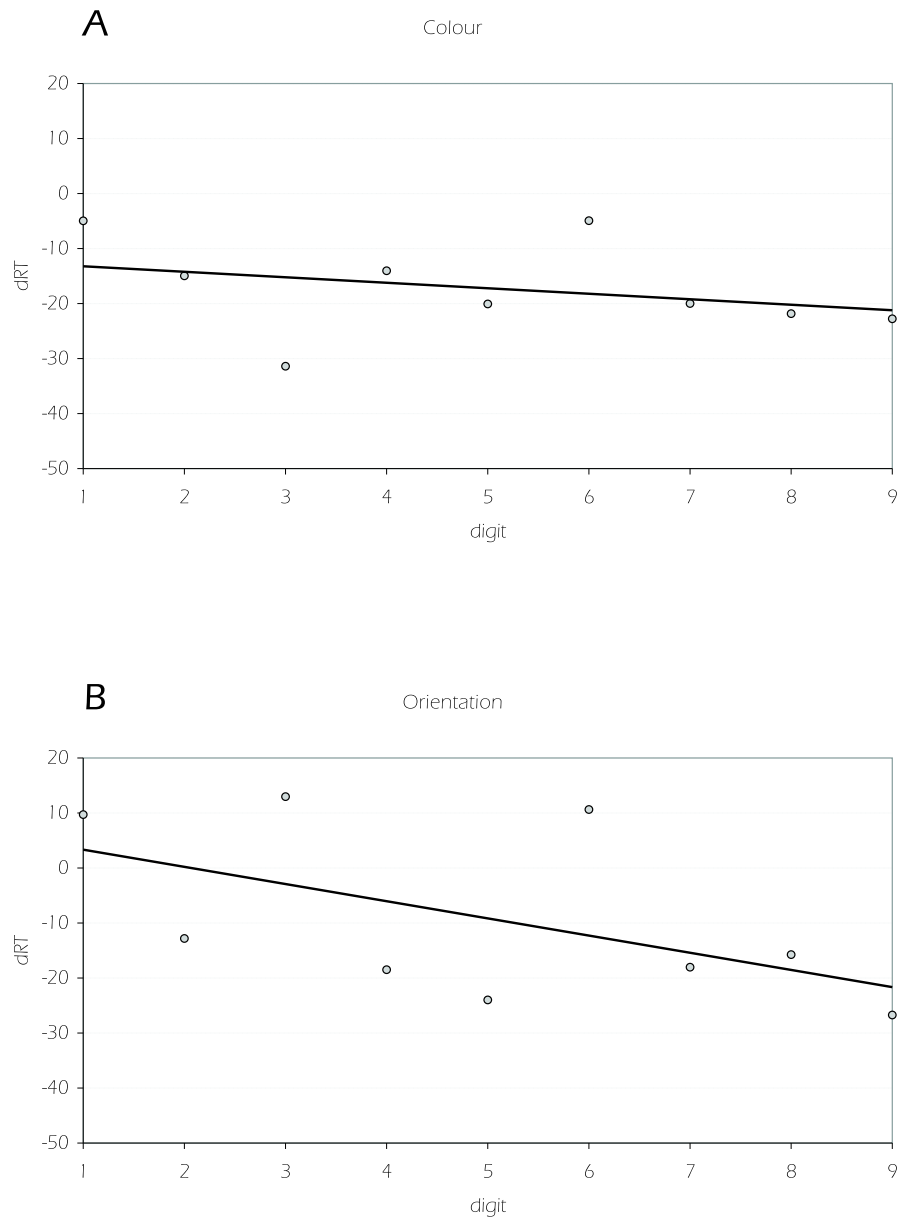


Figure 2.8: Experiment 7, differences in RT (dRT) between right and left hand responses (right minus left) as a function of the irrelevant digit for (a) the colour condition and (b) the orientation condition respectively. Circles indicate the observed dRTs. The continuous line depicts the predicted dRTs based on the regression analysis.

lacked a significant negative correlation between reaction time and percentage of errors (computed over 18 data couples, 9 numbers separated for left and right-hand responses), with $r(16) = -0.28$, $p < 0.27$ and $r(16) = 0.18$, $p < 0.47$ for the colour and orientation condition respectively. In the colour condition, the regression analysis of repeated measures revealed the following equation (See Figure 2.8):

$$dRT = -13.87 - 0.11 \times \textit{magnitude}$$

The magnitude of the individual slopes did not differ significantly from zero ($t(22) = -0.8$, $p = 0.94$, 12 participants had a negative slope), which means that magnitude did not contribute to the difference between left and right responses, and hence no SNARC-effect was obtained. The situation was different for the orientation condition, where the following equation was obtained (See Figure 2.8):

$$dRT = 6.46 - 3.12 \times \textit{magnitude}$$

In contrast to the colour condition, the slope was significantly different from zero ($t(22) = -2.26$, $p < .05$, with 14 participants showing a negative slope). This means that in the orientation condition a SNARC effect was present.

Importantly, the slopes obtained in the colour and orientation condition were significantly different from each other ($t(22) = 2.03$, $p < 0.05$, one-tailed).

2.2.4 Discussion

Even though colour was inherently coupled with the shape of the irrelevant number and required global processing of the stimulus (as was the case in Boucart et al., 1995), no semantic effects were obtained. Performing an orientation task on the same stimuli on the other hand, did result in the semantic processing of the irrelevant digits. The reason why our colour condition did

not reveal any signs of semantic activation of the irrelevant information (as opposed to Boucart et al., 1995) are not clear. Maybe it could have been the case that the specific stimuli used (vehicles and animals in Boucart et al., 1995 versus numbers in our experiment) require different amounts of activation before they are semantically processed. Whatever the reason is for this difference, the results of the present study are in line with the neural overlap hypothesis. Because orientation processing and number processing rely on similar neural processing regions, inhibiting number processing is less efficient, and hence a SNARC effect is obtained. Colour processing on the other hand employs different processing regions compared to orientation and hence form processing is easily inhibited, resulting in the absence of a semantic SNARC effect.

Chapter 3

The Simon effect is larger with spatial relevant information: a yet unidentified form of dimensional overlap¹

¹This manuscript is submitted for publication. Co-authors are Wim Notebaert, Wim Gevers and Wim Fias

Abstract

Four experiments were conducted to investigate contextual modulations of the Simon effect. The results showed that the Simon effect was quantitatively different depending on which kind of task needed to be performed. Importantly, this effect did not depend on the relative processing time of the relevant dimension, nor on a direct or indirect overlap between the relevant and irrelevant stimulus part. To account for the data, we suggest that dimensional overlap as defined by Kornblum et al. (1990) should be extended by adding similarity of processing domains as a case of dimensional overlap

3.1 Introduction

When we are trying to act upon the information reaching our retina, this mostly follows a specific chain of processes. We take up a lot of information, separate the relevant from the irrelevant information, and subsequently select the appropriate action. The principles upon which these selection and translation processes rely are not always as complex as one would expect. An example of such a basic principle is the similarity of attributes. When stimuli and responses are in some way compatible, this usually results in faster responding compared to incompatible stimulus-response (S-R) sets.

Apparently strong S-R compatibility (SRC) effects are obtained when the spatial dimension is involved (Fitts & Seeger, 1953). In a typical Simon task for example, people have to respond to a non-spatial attribute (let's say colour) of a peripheral stimulus by making a lateralised response. This means that (for this example at least) subjects have to make a left or right response to the colour of a stimulus that appears on the left or the right side of the screen. If the task-irrelevant stimulus location and the lateralised response correspond, this induces a congruency effect, referred to as the Simon effect (for a review see Simon, 1990).

3.2 Stimulus-response compatibility and the Simon effect

An important model describing stimulus-response compatibility (SRC) effects like the Simon effect is the dimensional overlap model proposed by Kornblum et al. (1990). According to this model compatibility effects arise because of overlap between relevant and irrelevant stimulus dimensions or between stimulus dimensions and response dimensions. Dimensional overlap was defined by Kornblum and his colleagues as the degree to which sets of items are perceptually, structurally, or conceptually similar. This means that dimensional overlap is not restricted to purely perceptual similarities, but also applies to the internal mental representations of the stimulus and response sets involved (Kornblum, 1994).

Procedural accounts describing congruency effects between relevant and irrelevant information start from the assumption that there are two routes involved in the course from stimulus to response (see De Jong et al., 1994; Kornblum et al., 1990). On the one hand there is the task-relevant pathway (also called the conditional route) responsible for the controlled processing of relevant information. This processing route is subject to the intentions of the human operator. On the other hand there is the task-irrelevant pathway (also referred to as the unconditional route) through which the irrelevant information is processed in an automatic fashion. In terms of cognitive control, dual-route models assume that relevant stimulus-attributes are processed under conscious control while attributes irrelevant for the task are processed effortlessly and without conscious control.

3.3 The orthogonal SRC effect

SRC effects like the Simon effect are not restricted to spatially parallel S-R correspondences but appear with many S-R correspondences. So, for instance, has it been demonstrated that spatial SRC effects emerge when stimulus and response attributes belong to orthogonal dimensions and as a consequence bear no direct spatial resemblance. Weeks and Proctor (1990) for example used vertical stimulus and horizontal response sets. In other words, participants observed stimuli appearing above or below a fixation point and they had to respond to this location with a left or right key press. They found that participants responded faster with right responses to stimuli presented above the fixation point, while stimuli presented below the fixation point were responded to faster with left responses. According to Weeks and Proctor (1990), this above-right/below-left advantage cannot be attributed to preferential motor effects, but originates from the cognitive coding at the S-R translation stage. A general theory explaining orthogonal SRC effects is the asymmetric coding account (see for instance Cho & Proctor, 2004, 2005; Proctor & Cho, 2003) which assumes that dimensional reference frames are ordered in terms of polarity (i.e. positive and negative). Specifically, this means that in the vertical dimension “above” is coded as positive and “below” is coded as negative, while in the horizontal dimension, “right” is coded as positive and “left” as negative. As a consequence, mapping up with right and down with left results in a structural correspondence of polarities between the stimulus and response codes and hence an SRC-effect is obtained.

Nishimura and Yokosawa (in press) were the first to systematically investigate orthogonal SRC in the context of the Simon effect. Contrary to Weeks and Proctor (1990), they made stimulus position irrelevant by letting participants respond with a right or left key press to the colour of a stimulus presented above or below the fixation point. They observed an orthogonal

Simon effect as indicated by an advantage for above-right/below-left combinations of the irrelevant stimulus position and the response.

3.4 A special case of SRC

Besides indirect correspondences like the orthogonal SRC and orthogonal Simon effects, evidence has been found that other types of correspondence also can influence the transition from stimulus to response. Fias, Lauwereyns, and Lammertyn (2001) and Lammertyn et al. (2002) demonstrated that irrelevant S-R translations can be modulated by the type of relevant stimulus attribute, even without a direct or indirect dimensional overlap. In these studies Fias et al. (2001) and Lammertyn et al. (2002) used the SNARC effect as a marker for irrelevant information processing. The SNARC effect is an effect closely related to the Simon effect. Its abbreviation stands for spatial numerical association of response codes and refers to the apparent spatial connotation attached to numbers. This effect was first reported by Dehaene et al. (1993) who subsequently suggested the idea that small numbers are associated with left, while large numbers are associated with right. This implicit association results in relatively fast left hand and slow right hand responses towards small numbers and vice versa for large numbers. In the study by Lammertyn et al. (2002) participants had to respond to either the colour or the orientation of a centrally presented number. According to dual-route accounts, the task-irrelevant number and its associated spatial information should be processed equally fast and automatic in the colour and orientation condition. Furthermore, there was no dimensional overlap for both the orientation and the colour condition between the relevant and irrelevant stimulus attributes and hence, the size of the SNARC effect should be similar for both conditions. The evidence is otherwise however: the SNARC effect in the colour condition was significantly smaller compared

to the SNARC effect in the orientation condition and this difference did not depend on temporal processing differences between both conditions. This assumes that the irrelevant numbers were processed qualitatively different for both conditions. The challenge is now to fit these results within a dimensional overlap framework. The fact that modulatory effects were found in the absence of a dimensional S-S overlap urges for a broader definition of dimensional overlap. For instance, it could be the case that dimensional overlap does not only result from direct associations within a dimension (i.e. SRC) or indirect associations from different dimensions converging onto a third dimension (i.e. orthogonal SRC), but also from associations between the processing domains that are involved (the “neural overlap hypothesis”, see Fias et al., 2001 and Lammertyn et al., 2002). This means that if two dimensions belong to the same processing domain (e.g. they are both spatial), this should also be considered to be a kind of dimensional overlap, as opposed to when there is no such “domanial overlap” (e.g. spatial versus colour).

3.5 The present study

One of the reasons we wanted to conduct this study is to find out if the differential processing of irrelevant information (as in Fias et al., 2001 and Lammertyn et al., 2002) is specific for implicit spatial information or not. Spatial information associated with irrelevant numbers is implicit and although it is generally believed that numerical information is automatically processed upon the mere exposure to numbers (Dehaene & Akhavein, 1995; Fias, Reynvoet, & Brysbaert, 2001; Koechlin, Naccache, Block, & Dehaene, 1999; Naccache & Dehaene, 2001; Cohen Kadosh & Henik, in press; Van Opstal, Moors, Verguts, & Fias, manuscript submitted for publication) it is not unthinkable that this kind of “inferred” information is more susceptible to

contextual modulation than would be the case with explicit spatial information. Salient spatial features like location have a strong association with their corresponding response. It is reasonable to assume that this strong association is less prone to modulation compared to when a less salient spatial feature, like the one associated with numbers, is used. Therefore we will now investigate dimensional overlap between processing domains within the Simon paradigm.

In addition, the choice of using the Simon paradigm is supported by the fact that Simon stimuli are generally believed to be processed within a dual-route architecture (Kornblum et al., 1990; De Jong et al., 1994). On top of that, Gevers, Caessens, and Fias (2005) and Gevers, Ratinckx, De Baene, and Fias (in press) showed that both the Simon effect and the SNARC effect are products of a similar dual-route processing architecture. The consequence of this is that possible differences between the Fias et al. (2001), Lammertyn et al. (2002) and the present study cannot be the result of basic processing differences.

The evident question is whether the Simon effect will also be modulated by the relevant task information. Our prediction is that the Simon effect will be different when the relevant and the irrelevant stimulus information belong to the same processing domain as opposed to when there is no such kind of S-S consistency. If this is indeed the case, this would imply that the definition of dimension overlap should be extended with similarity at the level of the processing domains involved.

3.6 Experiment 1

In Experiment 1, just as in the Fias et al. (2001) and Lammertyn et al. (2002) studies, two conditions are employed: a colour condition and an orientation condition. The prediction is that the size of the Simon-effect will depend

on the similarity of processing domains between the task being performed attentively and spatial character of the irrelevant stimulus position. This should result in a larger Simon effect for the orientation condition compared to the colour condition, because both orientation and stimulus position are spatial while no such overlap exists for the colour condition.

In 1993, Hommel demonstrated that irrelevant activation decays over time, resulting in larger Simon effects for fast responses in comparison to slow responses (see also Burle, Possamai, Vidal, Bonnet, & Hasbroucq, 2002 and Ridderinkhof, 2002). Based on this observation, another prediction would be that the decaying process demonstrated by Hommel (1993) will commence later or will be slower for the orientation condition than for the colour condition. To find out if this is indeed the case we will conduct a distribution-analysis.

3.6.1 Method

Subjects

Twenty Ghent University students enrolled for this experiment. Their mean age was 21.5 years ($SD = 5.7$), 13 of them were female and 15 of them were right-handed. All the participants gave informed consent and after they had finished the experiment they were paid €7.5. All the participants had normal or corrected-to-normal vision, and they were naïve with respect to the purpose of the experiment.

Apparatus & stimuli

A Pentium PC with a colour VGA display (resolution of 800×600 pixels and a vertical refresh rate of 70 Hertz) was used for controlling the experiment, showing the stimuli and timing the responses. Responses were registered with millisecond (ms) precision using response devices made by the faculty

technical staff. The experiment was programmed in C using the Tscope library (Stevens, Lammertyn, Verbruggen, & Vandierendonck, in press). For the orientation condition we used white filled equilateral triangles (RGB-value [230;230;230]). The triangle could be oriented upwards or downwards. For the colour condition we used red and green filled circles (RGB-values [230;0;0] and [0;230;0] respectively). All stimuli measured 1.2 visual degrees both horizontally and vertically. The vertically centred stimuli always appeared 2.9 visual degrees to the left or to the right from the midpoint of the screen.

For both the colour and orientation condition we used a 2 (feature status) \times 2 (stimulus position) design and for each cell 50 observations were administered. Eventually, this resulted in a total of 200 trials per condition.

Procedure

Each trial started with a white fixation point (a filled circle with a 3 pixel radius). After 1500 ms the fixation point was replaced by a blank screen. Another 350 ms later the stimulus appeared on the screen, either to the left or to the right of the midpoint of the screen. The response deadline was set to 1000 ms. After the participants responded to the orientation or to the colour of the stimulus the screen went blank and after an inter trial-interval of 1000 ms the next trial was initiated. Responses were made by using the index fingers of both hands on two vertically aligned buttons which were horizontally separated by approximately 13 cm.

Every 50 trials a break was inserted and the participants ran through the blocks at their own pace. On average a session lasted 35 minutes, breaks included. At the beginning of each condition the participants received a short description of the task they had to do and before the participants began with the experimental session they did a practice session of 20 trials. During the practice session, participants received immediate feedback about the accu-

racy of their response. The order of conditions (first colour, then orientation or vice versa) as well as the stimulus response-mapping was counterbalanced over participants.

3.6.2 Results

First, we checked if the participants responded differently depending on the specific stimulus-response mapping they had to use for the relevant task. This was not the case ($F < 1$, for both the orientation and colour condition separately). Furthermore, the orientation data were also checked for an orthogonal SRC effect between relevant and irrelevant stimulus information. Without result however: response times for congruent trials (triangles pointing up presented right or triangles pointing down presented left) were not responded to faster than incongruent trials (triangles pointing up presented left or triangles pointing down presented right), $t(19) = .07$ and $p = .94$.

Before running a 2 (Task) \times 2 (Congruency) \times 5 (Bin) within factors analysis of variance (ANOVA) on our data, we removed trials on which the reaction time was faster than 200 ms or slower than 1000 ms. This resulted in the removal of 1.3% of the data. After this we also removed those trials to which the participants had made the wrong response. This resulted in the removal of another 3% of the data. Mean RTs and error rates are presented in Table 3.1.

The reaction time data revealed the following results. There was a main effect of task ($F(1, 19) = 41.5$, $MSe = 440$ and $p < .001$) as well as a main effect of congruency ($F(1, 19) = 65.7$, $MSe = 427$ and $p < .001$). There was an interaction between task and congruency ($F(1, 19) = 6.9$, $MSe = 107$, $p < .05$) and planned comparisons showed that the Simon effect (congruent versus incongruent trials) was significant for both the colour and the orientation condition separately ($F(1, 19) = 28.8$, $MSe = 342$, $p < .001$ and $F(1, 19) = 98.4$, $MSe = 192$, $p < .001$ respectively). Importantly, this

Table 3.1: Mean reaction times (in ms) for Experiment 1 and 2. The percentage of errors is presented between parentheses.

	Experiment 1		Experiment 2	
	Orientation	Colour	Orientation	Colour
Congruent	397 (.02)	373 (.01)	413 (.022)	450 (.025)
Incongruent	440 (.05)	404 (.03)	455 (.048)	462 (.029)
Simon effect	43* (.03*)	31* (.02*)	42* (.024**)	12*** (.004)

* $p \leq .001$, ** $p \leq .01$, *** $p \leq .05$

Simon effect was larger for the orientation condition than for the colour condition ($t(19) = -2.6$, $p = .01$). For the error data the results followed a similar pattern except for the fact that the task by congruency interaction failed to reach significance ($F(1, 19) = 3$, $MSe = .000381$, $p \approx .098$).

Next, a distribution analysis was done (see Figure 3.1) using vincentized averaging for each bin (for more details see Ratcliff, 1979). This analysis resulted in a marginally significant three-way interaction between task, congruency and bin ($F(4,76) = 2.4$, $MSe = 132$, $p \approx .06$). When looking at each bin separately, the congruency effect was not statistically significant for bin 5 of the colour condition (although it was marginally so with $F(1, 19) = 3.71$, $MSe = 1264$, $p \approx .07$). For all the other bins of both conditions, the Simon effect was highly significant (all $p < .01$).

3.6.3 Discussion

Two important findings suggest that the automatic processing of the task-irrelevant information was modulated by the type of task being performed attentively. First, there was the observation that the Simon effect was statistically larger in the orientation condition compared to the colour condition. Furthermore, the bin-analysis confirmed that this difference has no temporal

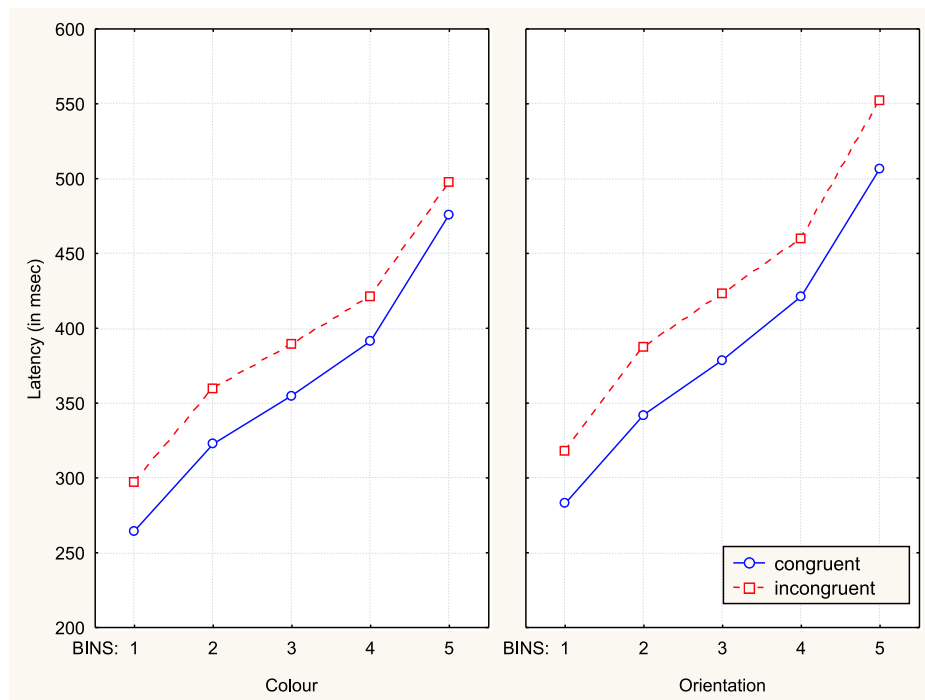


Figure 3.1: Bin-analysis for the colour condition (left) and the orientation condition (right) of Experiment 1. Each point represents the average reaction time of the corresponding quintile. Solid lines are used for the congruent condition and dotted lines for the incongruent condition.

restrictions: the Simon effect stays larger for the orientation compared to the colour condition both for fast, medium and slow RTs. Second, Hommel (1993) demonstrated that irrelevant activation decays over time, resulting in larger Simon effects for fast responses in comparison to slow responses (see also Burle et al., 2002 and Ridderinkhof, 2002). Overall, our data show that the RTs for the colour condition are faster than for the orientation condition. Based on the temporal characteristics of the Simon effect, normally one would expect a larger Simon effect in the colour condition. However, the reverse was true.

Together, these results point to a modulation of the Simon effect based on the dimensional overlap between the processing domains involved. How-

ever, before elaborating further upon possible mechanisms underlying this effect, we want to be sure that the interaction is not simply induced by the significant slower response times for the orientation condition. Therefore the current experiment was replicated making the colour condition more difficult in order to obtain better comparable RTs.

3.7 Experiment 2

In an attempt to increase the RTs for the colour condition we repeated Experiment 1 using colours that are more difficult to distinguish in the colour condition. The predictions remain identical as for Experiment 1: we expect a larger Simon effect for the orientation condition than for the colour condition.

3.7.1 Method

Subjects

For this experiment 16 students of the Ghent University enrolled (mean age was 21.4 years, $SD = 1.9$). Twelve of them were female and fifteen were right-handed. All the participants gave informed consent and after they had finished the experiment they were paid €7.5. All the participants had normal or corrected-to-normal vision, and they were naïve with respect to the purpose of the experiment.

Apparatus, Stimuli & Procedure

The same equipment and procedure were used as in Experiment 1. However, to make the colour condition more difficult the distinction between the two colours was now less salient compared to Experiment 1. This was done by setting the RGB values for the first colour to [188;133;43] and for the second colour to [124;155;44]. The luminance of both colours was 34 cd/m². The

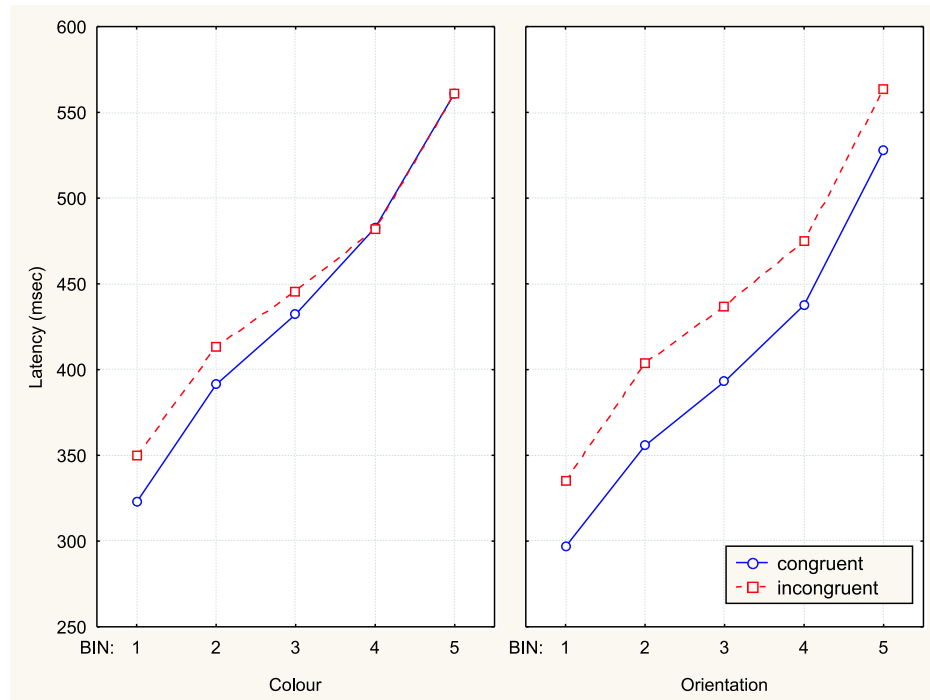


Figure 3.2: Bin-analysis for the colour condition (left) and the orientation condition (right) of Experiment 2. Each point represents the average reaction time of the corresponding quintile. Solid lines are used for the congruent condition and dotted lines for the incongruent condition.

RGB-values of the orientation condition stimuli were set to [145;145;145].

3.7.2 Results

Again we began by removing the outliers (0.8%) and the wrong trials (3.1% of the remaining data). Average response times and error rates can be found in Table 3.1. As was the case in Experiment 1, no effect of stimulus response-mapping could be revealed in the orientation and colour condition (both $F < 1$). Also, no up-right/down-left advantage between the orientation of the triangles and their position was present in the orientation condition ($t(15) = -0.47, p = .65$).

Responses for the colour task were significantly slower than for the orientation task with $F(1, 15) = 6.95$, $MSe = 1129$ and $p < .05$. Overall there was a significant Simon effect ($F(1, 15) = 42.17$, $MSe = 273$ and $p < .001$). Planned comparisons revealed that this congruency effect was significant for both the colour and the orientation condition separately with $F(1, 15) = 8.26$, $MSe = 141$, $p < .05$ for the colour condition and $F(1, 15) = 62.44$, $MSe = 221$, $p < .001$ for the orientation condition. Looked at in more detail, the Simon effect proved to be larger for the orientation condition than for the colour condition ($t(15) = 6.23$, $p < .001$). Also important, the interaction between the task and congruency also proved to be significant ($F(1, 15) = 38.86$, $MSe = 89$, $p < .001$).

The pattern of results for the error data was slightly different with only a marginal effect of task, but a significant main effect of congruency ($F(1, 15) = 4.43$, $MSe = .000264$, $p \approx .05$ and $F(1, 15) = 9.73$, $MSe = .000388$, $p < .01$, respectively). Planned comparisons showed that the congruency effect was only significant for the orientation condition ($F(1, 15) = 9.38$, $MSe = .006$, $p < .01$).

Just like in Experiment 1 we also performed a bin-analysis (see Figure 3.2). This analysis showed that with increasing RTs the Simon effect decreased in strength for the colour condition to completely decrease in the fourth bin, while for the orientation condition the Simon effect remained present until the last bin. This pattern was supported by a significant bin by congruency interaction for the colour condition ($F(4, 60) = 14.41$, $MSe = 89$, $p < .001$), and the absence of this interaction for the orientation condition ($F < 1$).

3.7.3 Discussion

Our manipulation resulted in overall slower RTs for the colour condition in comparison with the orientation condition (456 and 434 ms respectively).

Based on this information it is not surprising that the Simon effect was smaller for the colour condition than for the orientation condition. However, the bin-analysis provides us with reasons to believe that the smaller Simon effect in the colour condition is not solely attributable to relative slower response times because the effect is also smaller with relative fast response times and at comparable RT levels as in the orientation condition (see Figure 3.2).

The results of this experiment, combined with the results of Experiment 1 point to an effect of dimensional overlap which is based on similarity of the processing domains involved. However, it is still possible that the pattern of effects found in Experiment 1 and 2 is specific for attributes used. To exclude this possibility it is important to show that the effects found are not restricted to colour only, but can be extended to alternative ones such as shape.

3.8 Experiment 3

In this experiment we wanted to extend the findings of Experiment 1 and 2 to other features. More specifically we wanted to use another task-relevant feature because in the previous experiments this proved to be crucial for the effect to occur. Therefore shape now replaced colour as relevant attribute. The reasoning behind this choice is simple: just as colour, shape bears no processing resemblance with orientation. This means that the same dimensional and neural overlap effects are expected like in Experiment 1 and 2, namely a larger Simon effect in the orientation condition as compared to the shape condition.

3.8.1 Method

Subjects

Twenty Ghent University students participated in this experiment. Their mean age was 21 years ($SD = 1.8$). There were twelve females and 18 were right-handed. All the participants gave informed consent and after they had finished the experiment they received €7.5. All the participants had normal or corrected-to-normal vision, and they were naïve with respect to the purpose of the experiment.

Apparatus, stimuli & Procedure

Again we used the same equipment to control the experiment. The procedure was also identical to the previous experiments. Only the stimuli were different in a sense that the colour condition was replaced by a shape condition. The stimuli in the shape condition could be either a filled square or circle with identical dimensions as the orientation stimuli. Both the stimuli from the orientation condition and the shape condition were presented in the same colour (RGB-values [145;145;145]).

3.8.2 Results

Before analysing the data we removed trials with reaction times below 200 ms or above 1000 ms (2%). We only considered correctly answered trials and therefore we had to remove another 2.6% wrong trials (means and error rates can be found in Table 3.2). No effects were found of stimulus-response mapping ($F < 1$, for both the shape and orientation task) and in the orientation condition there was no up/right-down/left advantage between the vertical orientation of the triangles and their horizontal position ($t(19) = .44$, $p = .67$).

The reaction time data revealed that responses in the shape condition were faster than in the orientation condition ($F(1, 19) = 8.44$, $MSe = 2819$, $p < .01$). Also, congruent trials were faster compared to incongruent trials ($F(1, 19) = 35.69$, $MSe = 460$, $p < .001$). Unexpectedly, the interaction between these two factors (task and congruency) was not significant ($F < 1$). Planned comparisons showed that there was a Simon effect for both the orientation condition and the shape condition ($F(1, 19) = 26.9$, $MSe = 337$, $p < .001$ and $F(1, 19) = 33.3$, $MSe = 221.6$, $p < .001$, respectively). However, the size of the Simon effect was statistically not different for the shape and orientation condition ($t(19) = .67$, $p = .51$).

However, the picture was different for the error-data. Besides a significant main effect of both task and congruity ($F(1, 19) = 12$, $MSe = .00028$, $p < .01$ and $F(1, 19) = 15.76$, $MSe = .00097$, $p < .001$ respectively), the interaction between task and congruity was also statistically significant ($F(1, 19) = 4.85$, $MSe = .00037$, $p < .05$). There was a Simon effect for each condition separately ($F(1, 19) = 22$, $MSe = .000625$, $p < .001$ and $F(1, 19) = 4.6$, $MSe = .0007$, $p < .05$, for the orientation and shape condition respectively) and importantly, this Simon effect was larger in the orientation condition than in the shape condition ($t(19) = 2.20$, $p = .04$).

The RT bin-analysis showed similar effects for both tasks (see Figure 3.3). The Simon effect only seemed to last longer in time for the orientation condition than for the shape condition as shown by the presence of a (marginal) Simon effect for bin 5 in the orientation condition ($F(1, 19) = 4.22$, $MSe = 805$, $p \approx .05$) but not so in the shape condition ($F < 1$).

3.8.3 Discussion

Experiment 3 resulted in two important observations. First, by means of errors the Simon effect was larger for the orientation condition than for the shape condition. Second, for the reaction time data there was no difference

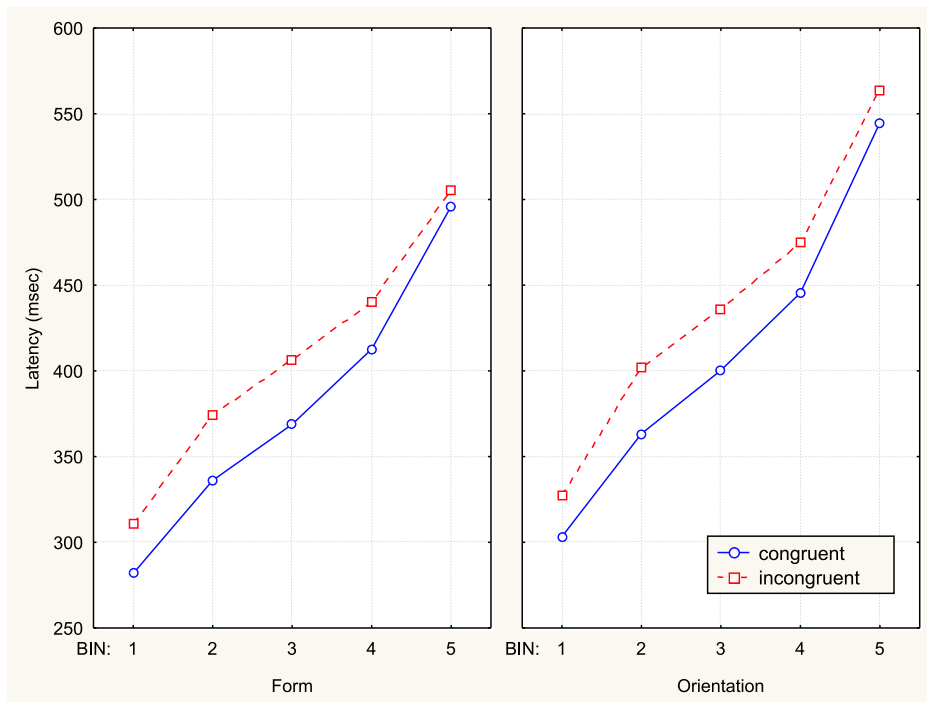


Figure 3.3: Bin-analysis for the shape condition (left) and the orientation condition (right) of Experiment 3. Each point represents the average reaction time of the corresponding quintile. Solid lines are used for the congruent condition and dotted lines for the incongruent condition.

between both conditions concerning the Simon effect. This is somewhat odd because based on the relative faster responses in the shape condition one would predict a larger Simon effect for the shape condition. The fact that this expected difference is cancelled out may possibly be the result of an enhanced Simon effect in the orientation condition which is caused by the overlap of processing domains between the relevant and irrelevant stimulus attributes.

Other evidence pointing towards dimensional modulation in the orientation condition can be found in the bin-analysis. There it is shown that the Simon effect is longer active for the orientation condition as demonstrated by the absence of an effect in bin 5 for the shape condition and a marginal

Table 3.2: Mean reaction times (in ms) for Experiment 3 and 4. The percentage of errors is presented between parentheses.

	Experiment 3		Experiment 4	
	Orientation	Shape	Orientation	Shape
Congruent	423 (.014)	390 (.01)	409 (.015)	468 (.023)
Incongruent	453 (.051)	417 (.028)	433 (.039)	482 (.017)
Simon effect	30* (.037*)	27* (.018***)	22* (.024**)	14** (-.006)

* $p \leq .001$, ** $p \leq .01$, *** $p \leq .05$

effect in the orientation condition in bin 5.

Together these results motivated us to further investigate the interaction of the Simon effect with the type of task-relevant stimulus attribute. To rule out the temporal dynamics of the Simon effect, Experiment 3 was replicated using a harder shape condition.

3.9 Experiment 4

In the previous experiment we used squares and circles as shape stimuli. This resulted in overall faster responses for the shape task compared to the orientation task. In an attempt to make the shape task slower, we will now use complex, meaningless 2-dimensional shapes as the ones employed by Cooper (1975).

3.9.1 Method

Subjects

For this experiment, 22 Ghent University students signed up. Their mean age was 24.3 years ($SD = 4$). Of them, 15 were female and 20 were right-handed. All the participants gave informed consent and after they had fin-

ished the experiment they were paid €7.5. All the participants had normal or corrected-to-normal vision, and they were naïve with respect to the purpose of the experiment.

Apparatus, Stimuli & Procedure

Experiment 4 was identical to Experiment 3 with this difference that for the shape condition we now used two random 2-dimensional shapes as the ones introduced by Cooper (1975). To acquaint the participants with the shapes, a learning phase was introduced just before the practice session of the shape condition. During this learning phase, the participants had to make a left or right response to the centrally presented shapes according to the stimulus response-mapping they were assigned to. Starting from the tenth trial, the accuracy was registered and the learning phase did not end before the participant had made a series of at least three correct responses for each shape. This algorithm set the minimal possible trials for the learning phase at 16. After the learning phase a normal practice session was run, followed by the experimental session. The Cooper stimuli we used were sized 1.9 by 1.9 visual degrees and had the same colour as the orientation stimuli (RGB-values [145;145;145]).

3.9.2 Results

In this experiment we had to remove 0.7% of the trials because participants responded too fast ($RT < 200$ ms) or too slow ($RT > 1000$ ms). Of the remaining trials we had to remove 2.4% of the data because of erroneous responses. Stimulus-response mapping did not have an effect on the reaction time-pattern ($F < 1$, for both the orientation and shape condition) and just like in all previous experiments there was no up/right-down/left advantage in the orientation condition between the orientation of the triangle and its position ($t(21) = .02$, $p = .98$).

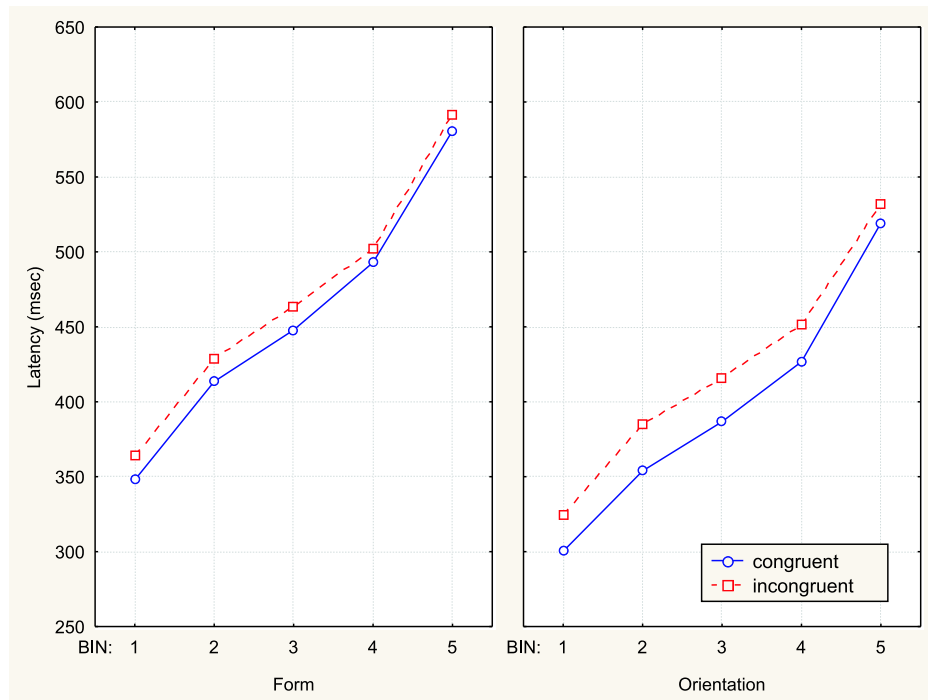


Figure 3.4: Bin-analysis for the shape condition (left) and the orientation condition (right) of Experiment 4. Each point represents the average reaction time of the corresponding quintile. Solid lines are used for the congruent condition and dotted lines for the incongruent condition.

The analysis of the reaction time data revealed a main effect of task ($F(1, 21) = 27.8$, $MSe = 2294$, $p < .001$) and a main effect of congruency ($F(1, 21) = 33.91$, $MSe = 236$, $p < .001$). Moreover, the interaction between task and congruency proved to be significant ($F(1, 21) = 5.27$, $MSe = 108$, $p < .05$). We also found a significant Simon effect for both the shape condition and the orientation condition (respectively $F(1, 21) = 12.14$, $MSe = 177.5$, $p < .01$ and $F(1, 21) = 38.6$, $MSe = 166.4$, $p < .001$). This Simon effect was larger in the orientation condition than in the shape condition ($t(21) = 2.3$, $p = .03$)

For the error data, the pattern was similar with a significant effect of task ($F(1, 19) = 8.32$, $MSe = .000142$, $p < .01$), a marginal effect of congruency

($F(1, 19) = 3.93$, $MSe = .000436$, $p \approx .06$) and a significant interaction between these two factors ($F(1, 19) = 13.8$, $MSe = .000364$, $p < .01$). Planned comparisons showed that the congruency effect was significant for the orientation condition ($F(1, 21) = 11.62$, $MSe = .00056$, $p < .01$) but not for the shape condition ($F < 1$).

The bin analysis revealed a similar pattern of effects as in Experiment 3 (see Figure 3.4).

3.9.3 Discussion

As opposed to Experiment 3 the RT data analysis revealed an interaction between task and congruency. It has to be noted though that the participants performed slower in the shape task compared to the orientation task. This means that one could simply attribute the smaller Simon effect in the shape task to the overall slower response. However, the distribution analysis takes the edge of this argument by showing that this difference occurs even for the fastest shape-responses.

Besides that, the error data show a clear modulatory effect caused by the overlap of processing domains between the relevant task and the irrelevant stimulus attribute. For these data there is no Simon effect in the shape condition (rather the reverse), while there is a large effect of congruency in the orientation condition. Together, these data show that dimensional overlap by domain is not specific for colour, but also applies when shape is used.

3.10 General Discussion

Four experiments were conducted to explore the boundaries of dimensional overlap as defined by Kornblum et al. (1990). Kornblum and his colleagues defined dimensional overlap as a structural, conceptual or perceptual simi-

larity between the attributes of stimuli and/or responses. It has been shown before that dimensional overlap can be the result from a direct correspondence between stimulus and response attributes (e.g. SRC), but also from indirect correspondences between stimulus and response attributes (e.g. orthogonal SRC, see Weeks & Proctor, 1990; orthogonal Simon, see Nishimura & Yokosawa, in press). What's more, the results of Fias et al. (2001) and Lammertyn et al. (2002) suggested that dimensional overlap is broader than direct or indirect correspondences between attributes. More specifically, Fias et al. (2001) and Lammertyn et al. (2002) demonstrated that if two dimensions belong to the same processing domain (e.g. they are both spatial), this also results in dimensional overlap effects, as opposed to when there is no overlap of processing domain (e.g. spatial versus colour). Because the irrelevant spatial information in the studies of Fias et al. (2001) and Lammertyn et al. (2002) was always implicit by nature (see Introduction) the present study was set up to test the assumption of dimensional overlap based on similarity of processing domains with explicit spatial information. Location information is explicit and therefore it is supposed to be automatically triggered and translated into a corresponding response code, leaving less space for modulation based on the overlap of the relevant and irrelevant processing domain.

To reach this aim, a typical Simon task set-up was used for all the experiments. In each experiment we combined two conditions which only differed by the type of relevant information applied. There was always an orientation condition together with a colour condition (Experiments 1 and 2) or a shape condition (Experiments 3 and 4). The irrelevant information was always the position of the stimulus relative to the centre of the screen (left or right) and responses were made by right or left key presses. This means that, because the irrelevant S-R relation was identical for all conditions, all differences between the orientation condition and the other conditions (colour or shape)

should be attributed to the type of relevant stimulus used.

The most important observation in this series of experiments is the fact that the way irrelevant information is processed depends on the type of relevant information employed. We observed a larger Simon effect with an orientation task than with a colour or shape task. Of significance here is the fact that the different sizes of the Simon effect are not caused by dissimilar time-courses underlying the processing of orientation versus shape, or orientation versus colour. In Experiment 1, responses for colour trials were substantially faster than for orientation trials. Although it is systematically observed that the Simon effect is larger with faster response times (Burle et al., 2002; Hommel, 1993) this did not result in a larger Simon effect for the colour condition. Quite the reverse was true: the Simon effect was larger for the orientation condition. This effect pattern remained the same in Experiment 2, although in this experiment the overall RT was slower for the colour condition compared to the orientation condition (similar observations were made in Experiment 3 & 4 with shape versus orientation).

While this is not the first demonstration that the supposedly automatic S-R conversion of irrelevant spatial information is susceptible to external influences (Caessens, Notebaert, Burle, & Soetens, 2005), the current findings are still remarkable. In terms of Kornblum's dimensional overlap model there is no overlap between the relevant information (colour or orientation) and the irrelevant location information. This means that the trials of both conditions should be classified under the Type-3 denominator, and hence congruency effects between the irrelevant location of the stimulus and the response should not be liable to modulations of the relevant stimulus type. The situation is different when you add similarities of processing domains to the definition of dimensional overlap. When relevant and irrelevant information bear some resemblance in terms of the domain they are processed within, this should also be seen as a form of dimensional overlap. As a consequence, the

orientation condition differs from the colour and shape condition because it contains overlap between the relevant and irrelevant stimulus attribute. The implications of this extended definition of dimensional overlap should not be underestimated. Our results show that even without direct categorical correspondences, similarities at the processing level can result in the modulation of congruency effects.

As an alternative explanation of the results, one could argue that the results found here are related to the orthogonal Simon effect. The relevant stimuli in the orientation condition were triangles pointing “up” or “down” which had to be responded to with “left” and “right” responses. While only half of the participants used the compatible S-R mapping (up press right, down press left), this could nevertheless have increased the overall Simon effect found in the orientation condition. However, it should be clear that the differences obtained between the orientation condition and the colour or shape condition are not caused by this kind of indirect associations. As shown in the results sections of all experiments, participants assigned to the “compatible” up-right/down-left mapping did not respond faster compared to participants instructed to use the “incompatible” up-left/down-right mapping. While this lack of an orthogonal Simon effect seems at odds with previous work (Weeks & Proctor, 1990; Nishimura & Yokosawa, *in press*) it is possible that orthogonal associations only emerge when more salient spatial features like location are employed. Besides that, there were no orthogonal S-S effects in the orientation condition which is another indication that orthogonal associations cannot be the direct cause of the modulation of the Simon effect. This observation is also in concordance with a recent study from Verbruggen, Liefoghe, and Vandierendock (2004). There they used left or right pointing triangles flanked by up or down pointing triangles and just as in the present study, no up-right/down-left advantage was obtained there (Verbruggen et al., 2004, p. 29). Together these results refute the alter-

native explanation that the differences between the orientation condition and the shape/colour conditions are the consequence of an indirect association similar to the up-right/down-left advantage. Rather, the difference should be ascribed to the overlap of processing domains in the orientation condition.

The concept of dimensional overlap based on processing similarities also makes sense at the neuro-anatomical level. If you assume that information belonging to the same domain is more likely to be processed by similar neural networks, it is not surprising that inhibition of irrelevant information will be less efficient when it belongs to the same domain as the relevant information. Therefore, the idea of modulatory effects caused by domain-specific similarities (and hence similarity of cognitive processes) is also in concordance with a neural overlap explanation (Fias et al. 2001; Lammertyn et al., 2002). With neural overlap defined as the similarity of neural processing structures involved, the same outcome would be predicted. Given the fact that spatial properties like orientation and the location of the stimulus are more likely to be processed in similar regions in the brain compared to for instance colour (see Fias et al. 2001), the neural overlap account assumes a greater interference between irrelevant and relevant information that is both spatial compared to when relevant and irrelevant information relies on different visual dimensions. This means that the neural overlap theory extends the dimensional overlap model by adding to it the possibility of modulatory effects caused by the similarity of neural regions involved by the processing of relevant and irrelevant stimulus properties.

To conclude, we can say that no existing model gives a satisfactory explanation for the results obtained here. Therefore we suggest to extend the definition of dimensional overlap by adding processing similarity, as a case of dimensional overlap. When relevant and irrelevant stimulus information belongs to the same processing domain (e.g. they are both spatial attributes) this should lead to increased congruency effects. It is important to under-

stand though, that processing similarity as such is not enough to create congruency effects. Assume that participants in our experiments do not have to press a left or right key, but have to give a (non-spatial) verbal response to the orientation, colour or shape of the lateralized stimuli. The verbal response excludes the dimensional overlap between the irrelevant dimension and the response dimension and as a result no congruency effects will be observed, even when there is processing similarity between the relevant and the irrelevant information. It is clear that the mechanisms explained here do not disprove the dimensional overlap model (Kornblum et al., 1990). At most we want to add to it the idea of modulatory effects driven by domainial and thus cognitive processing similarity as a means to explain the results obtained here.

Chapter 4

Generalizing the neural overlap hypothesis¹

¹Parts of this manuscript are prepared for publication. Co-authors are Jan Lauwereyns and Wim Fias

Up until now, the neural overlap hypothesis has found support in studies employing colour, shape and orientation stimuli. In all those experiments, orientation always served as the feature showing neural overlap with the processing of the irrelevant feature (numbers or spatial locations). Colour and shape, on the other hand, were consequently used as control tasks because relatively spoken, these show relatively less neural overlap with the irrelevant stimulus part.

The question is now if neural overlap is indeed a general mechanism. If this is indeed the case, then its scope should not be restricted to specific features or stimulus material, nor to specific processing regions. For this reason, this chapter will be dedicated to the investigation of the generality of the neural overlap hypothesis and we will do so in two series of experiments. In a first part we will try to find a replacement for orientation, while keeping the region of neural overlap the same as in previous experiments. In this way, we hope to find evidence that neural overlap principles also hold for other features than orientation. In the second part on the other hand, we will look neural overlap effects within other brain regions (i.e. the ventral processing pathway) in an attempt to prove that neural overlap is not an specific for the dorsal pathway.

4.1 Extending the neural overlap hypothesis at the feature level

4.1.1 Experiment 1: vertical and horizontal motion versus colour

Broadly spoken, the current experiment was not that much different from Experiment 6 of Chapter 2 (see also Lammertyn et al., 2002). Stimuli consisted of an irrelevant and relevant part, and the specific features were chosen

so that in a first condition there was neural overlap between the relevant and irrelevant part, while in a second condition such a neural overlap was less pronounced or even absent. In correspondence with the experiments of the second chapter, numbers served as the irrelevant stimulus part in all conditions. For the condition without neural overlap we once more reverted to colour as the relevant feature. With regard to the condition with neural overlap, however, we chose to replace orientation with motion.

Perceiving motion activates an extensive network of motion areas throughout the human brain (see Figure 4.1), including the human middle temporal cortex (MT+/V5), the human visual area V3A, the superior temporal sulcus (STS) and several regions in the intraparietal sulcus (IPS) (Culham et al., 2001; Sunaert, Van Hecke, Marchal, & Orban, 1999; Zeki et al., 1991; Tootell et al., 1995, 1997; Puce, Allison, Bentin, Gore, & McCarthy, 1998; Orban et al., 2003; Galletti & Fattori, 2003). On top of that, a recent study by Claeys, Lindsey, De Schutter, and Orban (2003) indicates the existence of two motion-processing systems: one lower-level system funneling motion information from MT/V5 and V3A into the IPS and STS, and a higher-level system represented in the inferior parietal lobule.

Because both low and high-level motion processing activates dorsal parietal regions, it makes a perfect candidate to serve as a neurally overlapping feature with number processing because number processing also relies substantially on parietal regions (Fias, Lammertyn, Reynvoet, Dupont, & Orban, 2003; Dehaene, Piazza, Pinel, & Cohen, 2003; Rusconi, Walsh, & Butterworth, 2005). To summarize, there will be two conditions: one motion condition in which number and motion processing neurally overlap and another colour condition with supposedly less neural overlap. In line with the results from Fias et al. (2001) and Lammertyn et al. (2002), our expectations are that a relatively larger SNARC effect will emerge in the motion condition compared to the colour condition.

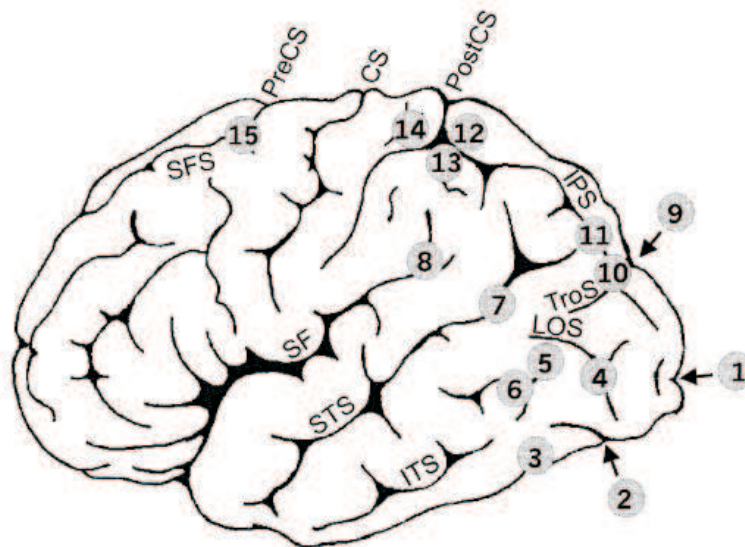


Figure 4.1: This figure shows a lateral view of the left hemisphere. Shaded numbered circles indicate the approximate centroid of suggested motion-responsive areas (adopted from Culham et al., 2001). (1) visual area V1, (2) lingual gyrus, (3) fusiform gyrus, (4) kinetic occipital (KO) area between MT+ and V3A (Van Oostende et al., 1997), (5) and (6) MT+ cluster, at the junction of the ITS and LOS (Watson et al., 1993), (7) STS, (8) posterior insular cortex (PIC), (9) parieto-occipital (PO) cortex, (10) V3A (Tootell et al., 1997), (11)-(14) motion-responsive IPS regions, (15) SFS. The following abbreviations are used: LOS: lateral occipital sulcus; STS: superior temporal sulcus; ITS: inferior temporal sulcus; TrOS: transverse occipital sulcus; IPS: intraparietal sulcus; PostCS: postcentral sulcus; CS: central sulcus; PreCS: precentral sulcus; SFS: superior frontal sulcus; SF: Sylvian fissure

Method

Participants Twenty-four students (8 men, 16 women) at the Victoria University of Wellington (New Zealand) participated in this experiment for course credit. Their mean age was 20.4 years ($SD = 4$) and eight of them were right handed. All participants had normal or corrected-to-normal vision and were naive with respect to the purpose of the experiment. One participant had to be excluded from the analysis because he appeared to be colour-blind.

Stimuli & Material The stimulus material used in this experiment was very similar to the material employed in Lammertyn et al. (2002), except for the fact that the numbers were always presented upright. Again Arabic digits from one to nine served as the irrelevant stimulus part. For the relevant part we used two features, namely motion or colour. During the motion condition, participants were required to indicate whether the numbers were moving in the horizontal or vertical dimension (the stimuli moved back and forward with an amplitude of 6 pixels and a frequency of approximately 3 cycles per second). For the colour condition a dominant colour-task was employed identical to the one used for Experiment 7 in Chapter 2.

The stimuli were presented on a 21-inch CRT-screen (vertical refresh rate 85 Hz; resolution of 1024×768 pixels). The participants were seated on a comfortable viewing distance of approximately 60 cm. All responses were registered to the nearest millisecond using a response device produced by the technical staff from the psychology faculty at the Ghent University. The response box was placed at a comfortable position in front of the participant and he controlled the device by using the index fingers of both hands. The response buttons on the response box were situated 4 cm to the left and 4 cm to the right of the middle of the device. The experiment was programmed in Tscope (Stevens et al., in press) and controlled using a Pentium PC.

Procedure The procedure was not different from the one in used in Lamertyn et al. (2002). Each participant completed a colour and motion condition and the order of the conditions was counterbalanced over participants.

Results

All wrong trials were removed before analyzing the data (4.7%). Those trials with response times falling outside the range subtending the grand average plus or minus three standard deviations were also discarded (7.3%).

A $9 \times 2 \times 2$ repeated measures analysis of variance (ANOVA) was conducted on correct RTs with number magnitude, task and response-side as within-subject variables. There was a main effect of number-magnitude and the mean RTs of correct responses were 559, 543, 538, 539, 549, 551, 552, 546 and 546 ms for the numbers 1 to 9 in ascending order ($F(8, 176) = 4.27$, $p < .001$). There was no main effect of task (colour 538 ms and motion 556 ms, $F(1, 22) = 1.57$, $p > .05$), nor an effect of response side (545 ms for right and 549 ms for left responses, $F < 1$). Moreover, none of the aforementioned variables interacted (all F 's < 1).

To find out if the irrelevant digits were processed semantically we evaluated the size of the SNARC effect (Dehaene et al., 1993). The SNARC effect stems from an association between the position of numbers on a left-to-right oriented number line and the response side. If this is indeed the case, this predicts a negative relation between number magnitude and the RT difference between right and left responses. The presence of a SNARC effect was investigated by using a regression analysis of repeated measures data as described by Lorch and Meyers (1990). This method includes the following steps. First, to investigate the presence of the above-mentioned negative relation between number magnitude and the RT difference between right and left responses, average RTs of the correct responses are computed for each subject and this separately for left and right responses. Based on these means,

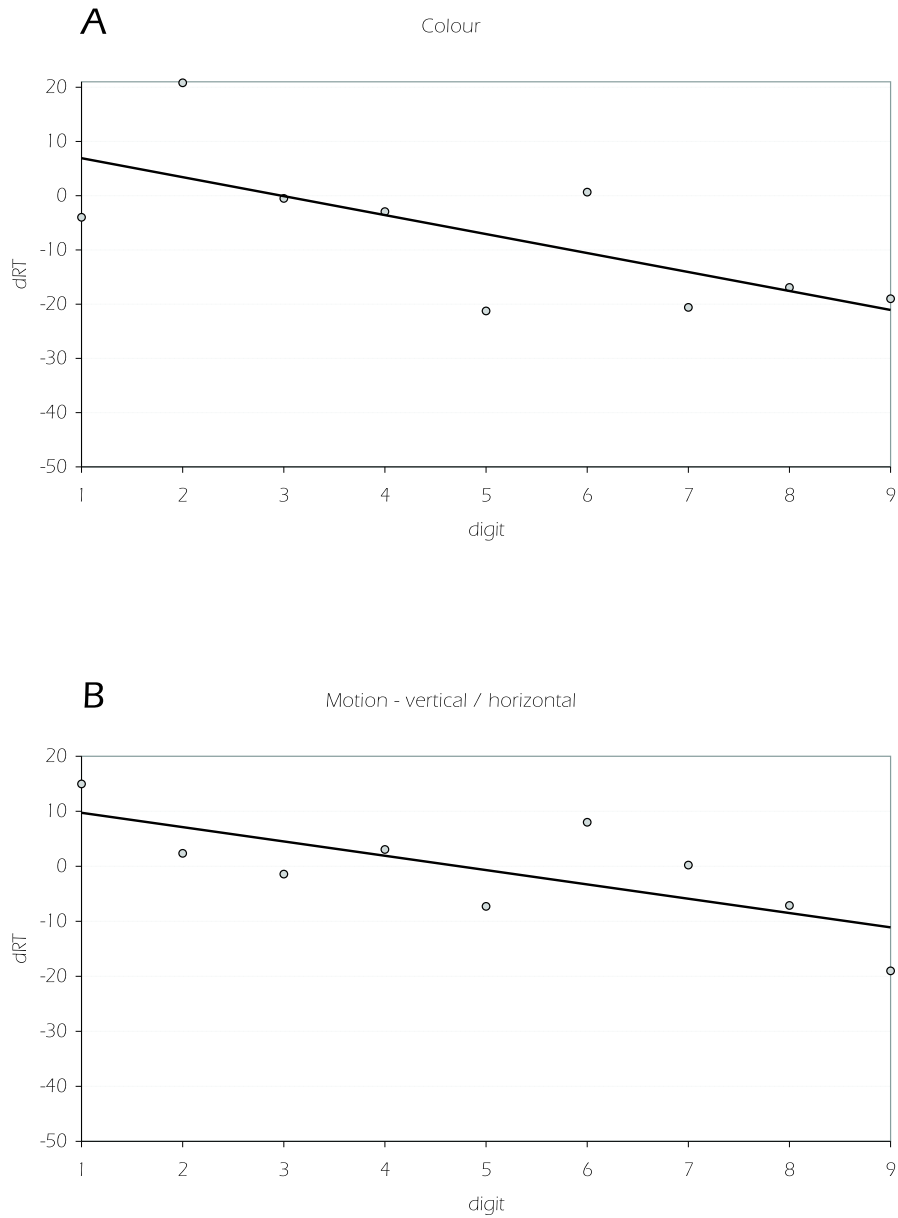


Figure 4.2: Experiment 1, differences in RT (dRT) between right and left hand responses (right minus left) as a function of the irrelevant digit, for (a) the colour condition, and (b) the motion condition. Circles indicate the observed dRTs. The continuous line depicts the predicted dRTs based on the regression analysis.

differences in RT (dRTs) are computed by subtracting the average RT for the left hand from the average RT for the right hand. In a second step, a regression equation has to be computed per subject with number magnitude as predictor variable. And finally, in a third step, t-tests are performed to test whether the regression weights of the group deviate significantly from zero (the advantages of adopting this method are previously described in Fias et al., 1996).

The regression analysis of repeated measures data revealed the following equations (see Figure 4.2):

$$\begin{aligned} \text{colour: } dRT &= 9.21 - 3.5 \times \text{magnitude} \\ \text{motion: } dRT &= 12.32 - 2.6 \times \text{magnitude} \end{aligned}$$

The slopes obtained from the regression analysis with digits as predictor proved to be marginally different from zero and this was the case for both the colour and the motion condition (*colour*: $t(22) = 1.76$, $p = .09$; *motion*: $t(22) = 1.95$, $p = .06$). In absolute terms the slope for the colour task was steeper than the slope in the motion task, but a paired t-test showed that the slopes obtained for both tasks did not differ significantly from each other ($t(22) = .45$, $p = .66$).

Discussion

The results of this experiment are not straightforward. A (marginal) SNARC effect emerges for both the condition with and without neural overlap. This does not refute the neural overlap hypothesis, because statistically spoken there was no difference between both conditions. However, this null effect downgrades all attempts to pinpoint the reasons behind this absence to ad hoc explanations and speculation. Nevertheless, to be able to avoid this in future experiments it might be interesting to reflect on possible reasons for this failure to obtain neural overlap effects. One reason may be that

neural overlap is not a general mechanism. This could mean that the results from Fias et al. (2001) and Lammertyn et al. (2002) should be explained by the specific feature used, signifying that neural overlap only arises with orientation as relevant feature. On the other hand, it is also possible that the implementation of motion in the current experiment was not ideal. Two types of motion were used, namely vertical and horizontal movement. This may have enhanced the saliency of the numbers even in the colour task because the horizontal movements from the left to the right and vice versa are associated with the same structural dimension as numbers (Dehaene et al., 1993; Seron, Pesenti, Noel, Deloche, & Cornet, 1992; Brysbaert, 1995; Fias, 2001; Fias et al., 1996; Ratinckx & Brysbaert, 2002, but see Ito & Hatta, 2004). This hypothesis was also confirmed by an additional ANOVA where task, SNARC compatibility² and motion dimension (horizontal versus vertical) served as within-subject variables. Overall, this analysis revealed a main effect of motion dimension (558 ms for horizontal versus 539 ms for vertical trials; $F(1, 22) = 37.78, p < .001$) and an interaction between task and motion dimension ($F(1, 22) = 22.78, p < .001$). Important for our case however is the fact that the (marginal) SNARC effect obtained in the colour task is primarily due to the horizontally moving numbers (see Figure 4.3). Planned comparisons in the colour condition show that the SNARC effect is significant for the horizontal dimension ($F(1, 22) = 5.04, p < .05$), while it is not for the vertical dimension ($F < 1$).

While the mechanisms behind these differential effects for horizontal and vertical moving numbers are not fully understood, it is clear that they should better be avoided. To rule out this latter explanation we designed a new experiment, but this time however, only using vertical moving stimuli.

²left responses to numbers smaller than five and right responses to numbers larger than five are considered SNARC compatible, while left responses to numbers larger than 5 and right responses to numbers smaller than five are considered as SNARC incompatible

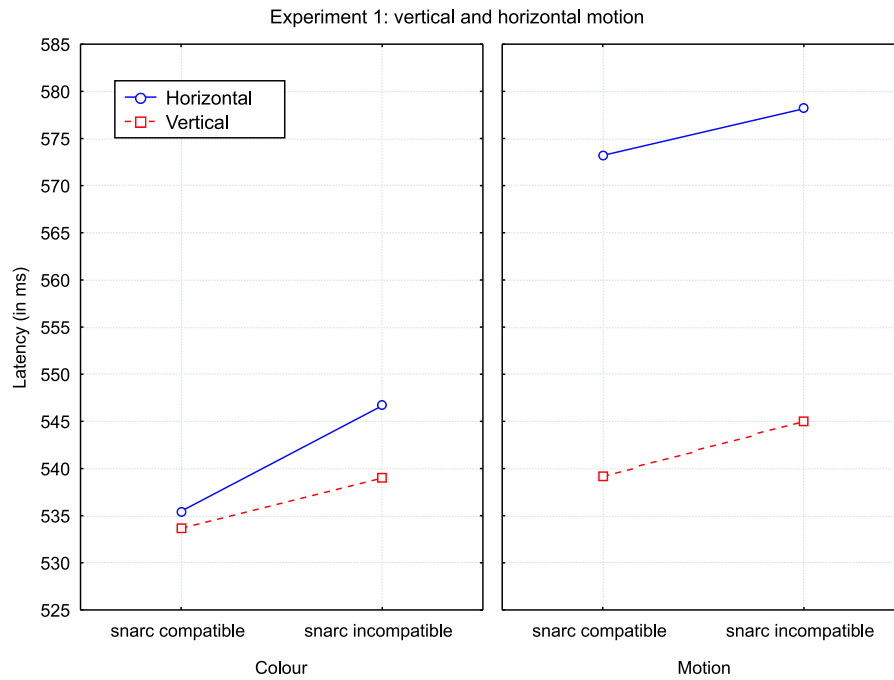


Figure 4.3: Experiment 1 data split up for trials with horizontal and vertical moving numbers

4.1.2 Experiment 2: up/down motion versus colour

In Experiment 1 we used motion in combination with numbers to create the neural overlap condition. The implementation of motion in this experiment may not have been ideal though. Because we used motion in both the vertical and horizontal dimension, the horizontal moving stimuli followed the same orientation as the mental number line, touching upon its characteristics directly rather than indirectly. To avoid this possible source of undesired interference in the colour condition, only vertical motion will be used in this experiment. This means that subjects will have to identify the direction of an up or downward moving digit. All other details of this experiment are kept identical to the previous experiment.

Method

Participants Eighteen students (13 women, 5 men) from the Victoria University of Wellington (New Zealand) participated in this experiment to receive course credit. Their mean age was 20.2 years ($SD = 3.2$) and one of them was left handed. All participants had normal or corrected-to-normal vision and were naive with respect to the purpose of the experiment.

Stimuli, Material & Procedure There was only one difference between the present experiment and Experiment 1. Motion was now restricted to the vertical dimension. The motion-path extended twenty pixels up or down, starting from the centre of the screen and with a velocity of 10 pixels per second. Subjects responded to the direction of the moving stimuli during the motion condition and did so with a right or left key press. The stimulus-response mapping was counterbalanced over participants.

Results

First, 7.9% of the trials had to be excluded from the analysis because they fell well outside the range of the grand average plus or minus three standard deviations. On average, the participants made 11.7% errors.

A $2 \times 9 \times 2$ repeated measures ANOVA with task, number magnitude and response side as within-subject variables only revealed a main effect of task. Response times of trials belonging to the motion condition were statistically faster than colour condition trials (387 ms versus 471 ms respectively, $F(1, 17) = 52.5, p < .01$). The main effect of number magnitude was marginally significant. The average RTs for the digits 1 to 9 were, respectively, 434, 430, 431, 429, 422, 423, 435, 429 and 429 ms ($F(8, 136) = 1.73, p \approx .09$). There was no difference between left or right hand responses, and no interactions between any of these variables (all F 's < 1).

Differences in response time between right and left hand responses as a

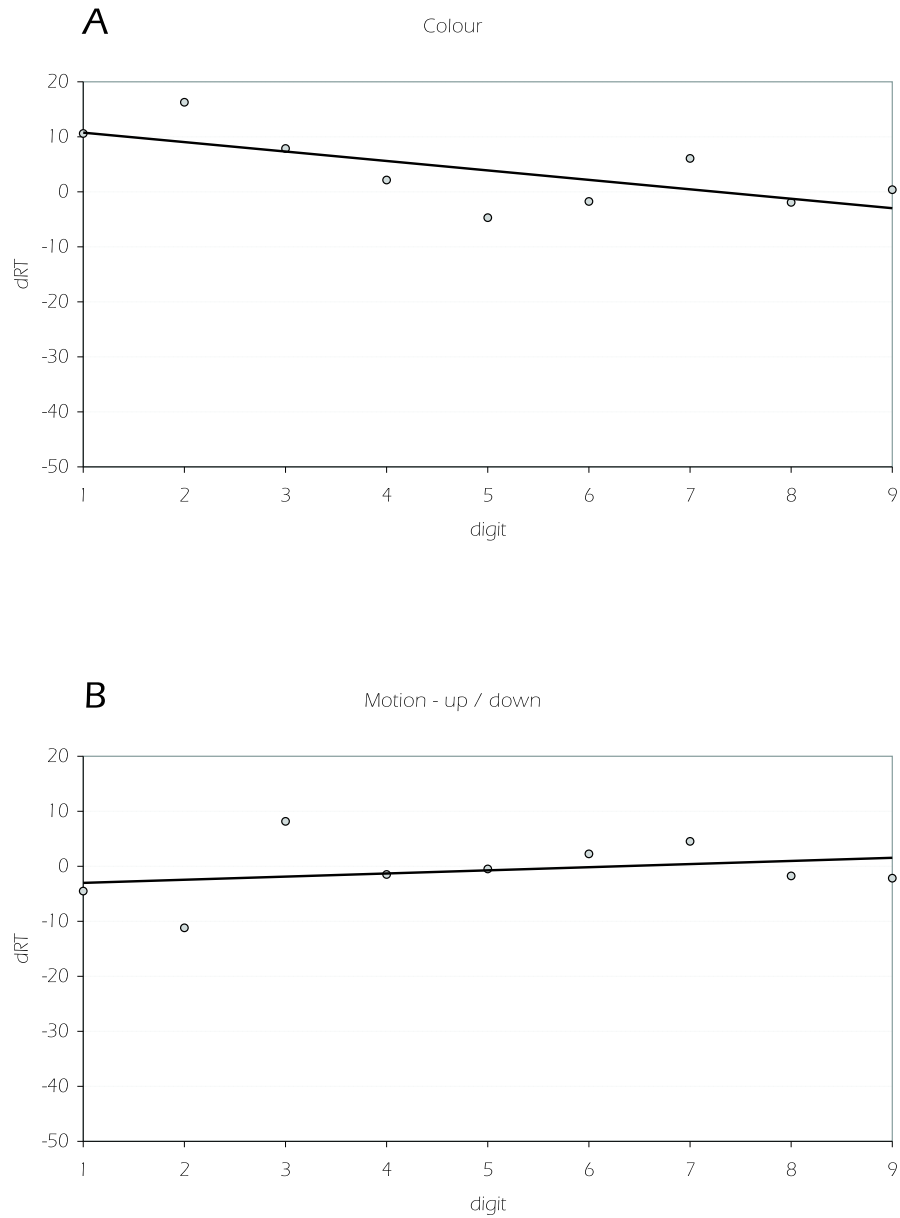


Figure 4.4: Experiment 2, differences in RT (dRT) between right and left hand responses (right minus left) as a function of the irrelevant digit, for (a) the colour condition, and (b) the motion condition. Circles indicate the observed dRTs. The continuous line depicts the predicted dRTs based on the regression analysis.

function of number magnitude for both the colour and motion condition are presented in Figure 4.4. The regression analysis of repeated measures data revealed the following equations:

$$\text{colour: } dRT = 12.47 - 1.72 \times \text{magnitude}$$

$$\text{motion: } dRT = -3.58 + 0.57 \times \text{magnitude}$$

The slopes from both the colour and motion condition were statistically not different from zero (*colour*: $t(17) = -1.56$, $p = .14$; *motion*: $t(17) = .75$, $p = .47$). The difference between the slopes from the colour and motion condition was statistically not different ($t(17) = 1.51$, $p = .15$), although in absolute terms the motion slope was positive as opposed to the negative colour condition slope.

Discussion

It has been shown before that motion and number processing share similar neural processing circuits while this is less the case for colour and number processing. Departing from this knowledge and in line with the neural overlap hypothesis, we predicted more interference from the irrelevant numerical information (and hence a larger SNARC effect) when motion discrimination was the main task, compared to when a colour task had to be performed. The results of this experiment do not confirm these predictions. The sole use of vertical motion, instead of combining vertical and horizontal motion (as in Experiment 1) did not alter the results. Once more, no SNARC effects were obtained for both conditions. More importantly, however, the slopes obtained for the colour and motion condition were not different from each other. This means that also in this experiment, no evidence is found for the neural overlap hypothesis.

The results may have been biased however by the relative speed difference between the colour and motion condition: the response times for the colour

condition were much faster than for the motion condition. This is a factual problem since it has been shown before that the SNARC effect increases as a function of the time that is needed to respond (e.g. Gevers et al., 2005). Actually, this means that the failure to obtain a difference between the colour and the motion condition may be totally attributed to the relative speed difference.

For this reason, it is necessary to follow up this experiment and try to equalize the RT levels of both conditions.

4.1.3 Experiment 3: vertical and horizontal motion versus colour

The current experiment has the same objectives as the previous experiment. This time however we will try to keep the RT levels for all conditions equal by making the colour task harder by using less distinguishable colour patterns.

Besides that, we will also try to maximize chances for a SNARC effect to develop. For this purpose, only small and large numbers will be used. This strategy has been used before and evidence supporting its utility to obtain large SNARC effects can be found in studies by Gevers et al. (2005, in press).

Again, our predictions are in line with the neural overlap hypothesis: we expect a larger SNARC effect for the motion condition compared to the colour condition. However, if this is not the case and no SNARC effects are obtained in none of the conditions, we need to elaborate further upon the probability of irrelevant digit effects within a motion paradigm.

Method

Participants Twenty first-year psychology students (18 women, 2 men) at the Ghent University participated in this experiment to gain course credits. On average they were aged 18.25 years ($SD = 0.55$). Two participants were

left handed and all of them had normal or corrected-to-normal vision. The participants were naive with respect to the purpose of the experiment.

Stimuli, Material & Procedure Exactly the same procedure was used as in Experiment 2. Only at the level of the stimuli some changes were carried out. First, the set of numbers used was now restricted to the extreme values 1, 2, 8 and 9. Secondly, we lowered the proportion of dominant coloured pixels to slow down colour trials and make them RT-wise more comparable to motion trials.

Results

Before doing the analysis we removed 0.6% fast (< 200 ms) or slow (> 1000 ms) outliers. On average, participants made 3.6% errors.

A $2 \times 4 \times 2$ repeated measures ANOVA was conducted on the correct RTs using three within-subject variables, namely task, magnitude and side of response. There was only a significant main effect of response hand. Right-hand responses were faster than left-hand responses (477 ms versus 498 ms, $F(1, 19) = 10.22$, $p < .01$). Reaction times for colour trials were slightly slower than for motion trials, but this difference failed to reach significance (colour: 492 ms; motion: 483 ms, $F < 1$). The main effect of digits was marginally significant ($F(3, 57) = 2.39$, $p \approx .07$) and the average RT for the numbers 1, 2, 8 and 9 were respectively 492, 485, 489 and 486 ms.

The regression analysis of repeated measures data revealed the following equations (see Figure 4.5):

$$\text{colour: } dRT = -14.18 + 0.51 \times \text{magnitude}$$

$$\text{motion: } dRT = -31.48 + 0.39 \times \text{magnitude}$$

The positivity of the slopes obtained for both the colour and motion condition indicates that no SNARC effect was present. Furthermore, these

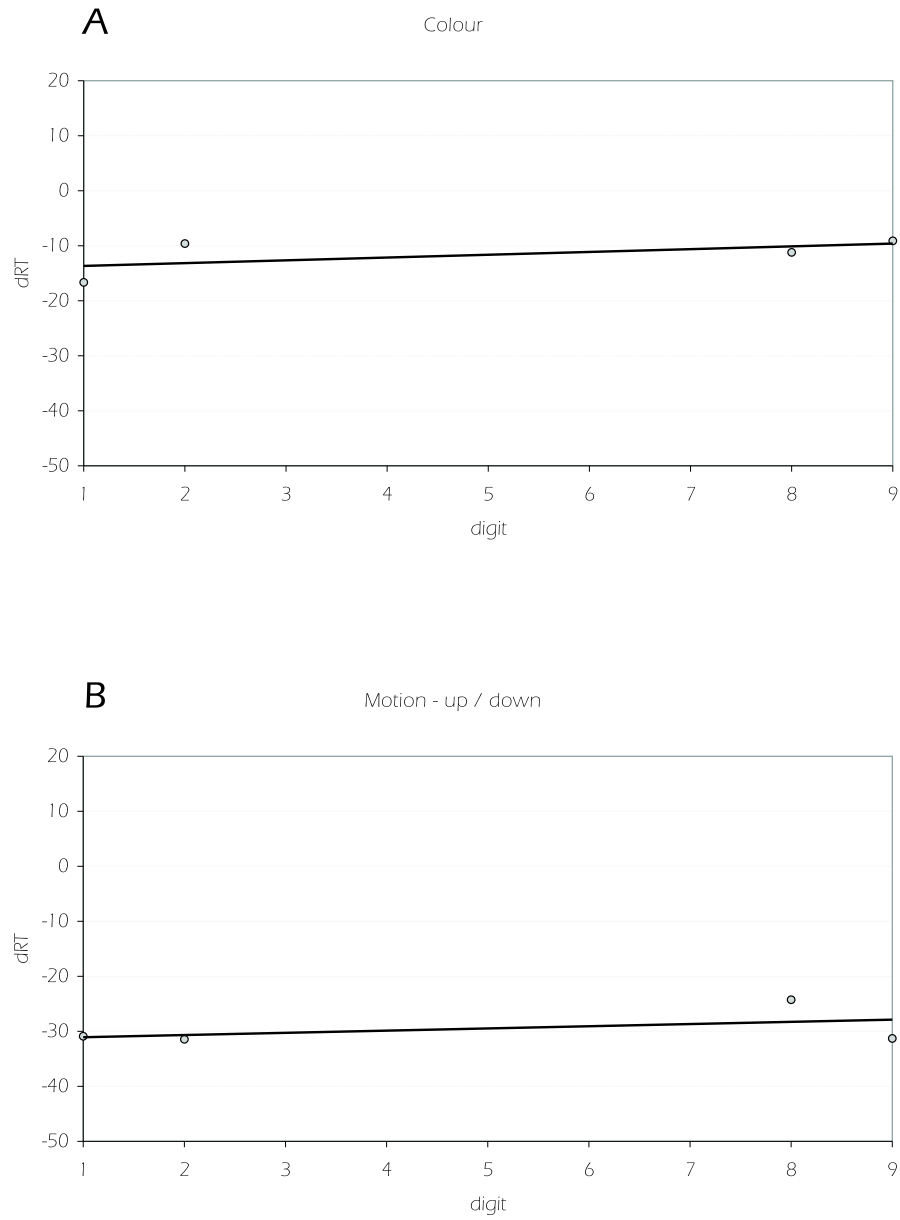


Figure 4.5: Differences in RT (dRT) between right and left hand responses (right minus left) as a function of the irrelevant digit, for (a) the colour condition, and (b) the motion condition. Circles indicate the observed dRTs. The continuous line depicts the predicted dRTs based on the regression analysis.

positive slopes did statistically not deviate from zero: *colour*: $t(19) = .44$, $p = .67$; *motion*: $t(19) = .56$, $p = .58$. Important for our case however was the fact that the slopes obtained for both tasks did not significantly differ from each other, as witnessed by the paired comparison between the two ($t(19) = .1$, $p = .92$).

Discussion

In this experiment we tried to find evidence for the neural overlap theory by opposing a neural overlap condition against a condition lacking neural overlap. Building on the previous experiment we changed two elements. First, we succeeded in leveling the RT level between the two conditions and this was achieved by making the colour condition harder and thus slower. Secondly, we employed ideal conditions for a SNARC effect to emerge. This manipulation did not have an effect however since there was no SNARC effect in both conditions. This finding combined with the results of Experiment 1 and 2 raises questions about the mere possibility of obtaining a SNARC effect with moving numbers. Another issue concerns the question if attention can be selective for the colour of a moving object without processing the object itself, as this possible selection inefficiency might have wiped out the differences between the two conditions.

In order to solve the colour or motion task, tracking the moving object is obligatory. Decoupling features like motion and colour is infeasible when they are properties of the same object. This, because it is probably impossible to derive the colour from a moving target without updating its position in time and space (e.g. Tsal & Lamy, 2000; Sohn, Chong, Papatomas, & Vidnyanszky, 2005). This is directly related to the binding problem (Treisman, 1996) because this means that to be able to respond to the colour of a moving object, one has to synchronize the position of the object and the attended feature belonging to this object both in time and space. A possible

side effect of having to track the object in time and space while deriving its colour is that this makes it almost impossible to efficiently inhibit the identity of the moving object. Even more, it is probably harder to inhibit the identity of a moving object while trying to find out its colour than to ignore its identity while detecting the direction it is moving in. Deriving the direction of a moving object in a two-dimensional space does not necessarily require to track the object because the changes of luminance are not only bound to the place where the object is, but also to where it has been before. Although no direct evidence is obtained for this in our experiments, attending local luminance changes on a local part of the display often is a more parsimonious way to tell the direction of a moving object, especially when only two directions are employed and you have to ignore another irrelevant feature belonging to the same object simultaneously.

To summarize, while it is not totally clear why there was no difference of SNARC effects between the two conditions, attentional differences might have played a role. Therefore, to avoid problems with object-tracking or local attention solutions we conducted the next experiment.

4.1.4 Experiment 4: dot motion versus colour

In all of the previous three experiments we implemented motion by making the irrelevant object (an Arabic digit) move by itself. Some would argue that this type of motion requires the object to be identified and represented as a whole, which undermines our intention to keep the object irrelevant. To circumvent this possible critique we will now revert to stationary digits. Motion will be implemented by making dots move within the outlines of the irrelevant digit.

Our predictions regarding the neural overlap hypothesis do not change: for the neural overlap hypothesis to be generalized we should obtain a larger SNARC effect in the motion condition compared to the colour condition.

The base for this difference lays in the relation of processing regions, which is relatively larger for numbers and motion compared to numbers and colour.

Method

Participants Sixteen Ghent University students (10 women, 6 men) enrolled for this experiment and received a €7.5 participation fee after they had finished the experiment. Their mean age was 25.3 years ($SD = 6.1$) and three of them were left handed. All participants had normal or corrected-to-normal vision and were naive with respect to the purpose of the experiment.

Stimuli & Procedure In this experiment we used stationary outlined numbers as irrelevant information. For the motion condition the inner plane of the digit was filled with moving dots ($n = 600$). Seventy-five percent of these dots moved in a starfield-like fashion, which means that they were either moving from the centre outwards, or alternatively, from the border towards the center. The remaining 25% of the dots followed a random path starting from a random position in the presentation field. Combining orderly and randomly moving dots made it impossible to solve the motion task by focussing attention to a small local part of the stimulus. None of the moving dots changed direction during one trial. The participants were told to press a left or right key depending on whether the majority of moving dots moved towards them or away from them. Care was taken that the participants fully understood the instructions, and this was explicitly checked after the practice session. The colour condition was similar to the previous experiments. The number was filled with red and green coloured dots of which one colour was overrepresented and participants had to indicate the dominant colour by pressing a left or right key.

This time, number 1 and 9 were left out of the number set, because pilot tests showed that the narrow body of number 1 hinders the perception of

the motion direction. To maintain an equal number of digits at each side of the number 5, we also left out number 9 of the stimulus-set. There were no procedural differences with the previous experiment.

Results

Before analyzing the data trials with responses faster than 200 ms or slower than 1000 ms were excluded (0.7%). On average the participants made 5.3% errors.

A $2 \times 2 \times 7$ repeated measures ANOVA with task, response side and number magnitude as within variables resulted in main effects for all three variables. Responses in the colour condition were faster than in the motion condition (420 ms versus 513 ms, $F(1, 15) = 47.92$, $p < .01$), right hand responses were faster than left hand responses (456 ms versus 477 ms, $F(1, 15) = 8.87$, $p < .01$) and finally, the reaction times varied depending on which number was presented ($F(6, 90) = 5.6$, $p < .01$). Mean RTs of correct responses with the digits 2 to 8 as irrelevant information were respectively, 472, 465, 465, 459, 469, 474 and 461 ms. None of the interactions between the three variables reached significance (all F 's < 1).

In Figure 4.6 you will find the difference for the colour condition between right and left hand responses as a function of number magnitude. The related regression weights resulted in the following equation:

$$dRT = -16.9 - 0.69 \times magnitude$$

For the motion condition, the regression analysis of repeated measures data revealed the following equation:

$$dRT = -21.2 + 0.005 \times magnitude$$

Again, the slopes obtained from the regression analysis with digits as predictor were not different from zero and this for both the colour and the

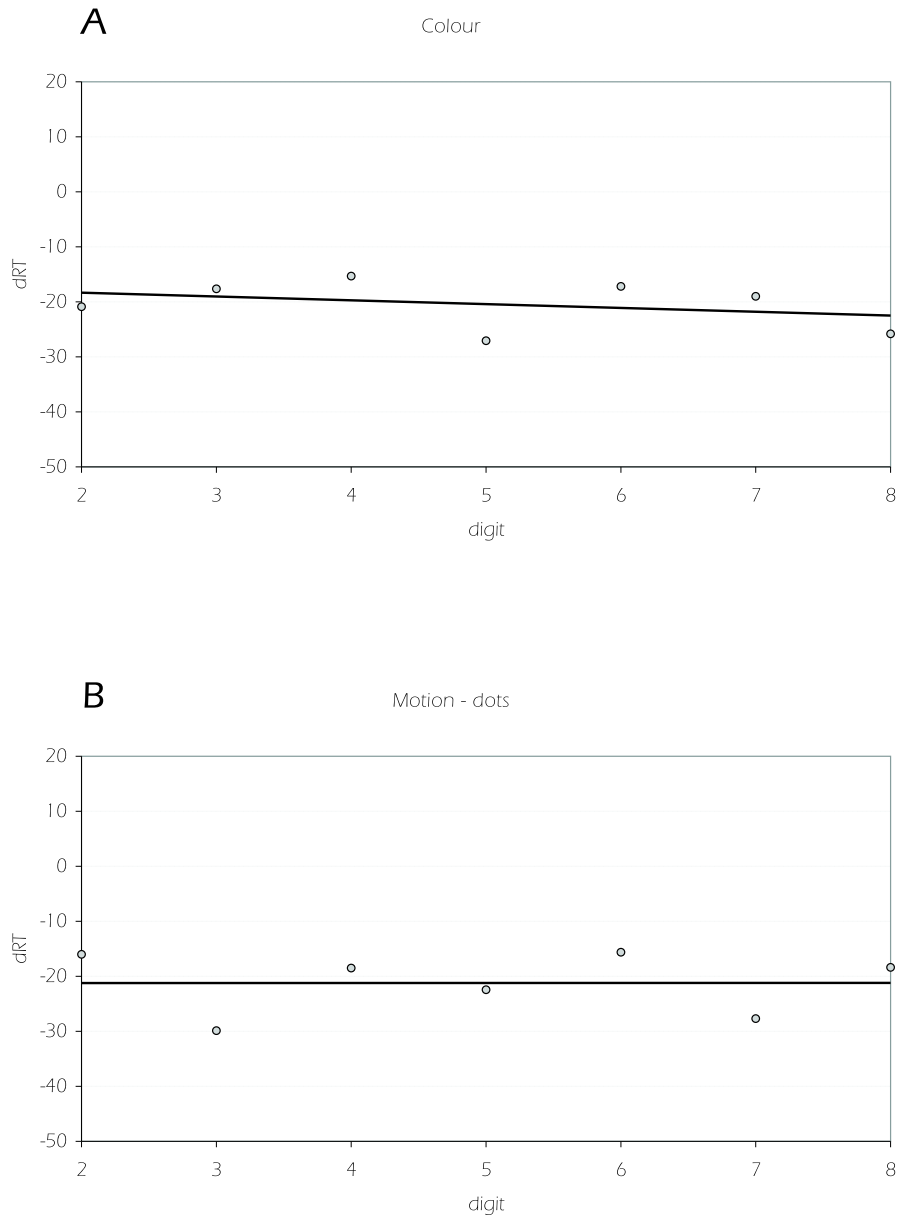


Figure 4.6: Differences in RT (dRT) between right and left hand responses (right minus left) as a function of the irrelevant digit, for (a) the colour condition, and (b) the motion condition. Circles indicate the observed dRTs. The continuous line depicts the predicted dRTs based on the regression analysis.

motion task (*colour*: $t(15) = -.46$, $p = .65$; *motion*: $t(15) = 0$, $p = 1$). In absolute terms the slope from the colour task was negative and the slope from the motion task positive, but a paired t-test showed that the slopes obtained for both tasks did not differ significantly from each other ($t(15) = 0.3$, $p = .8$).

Discussion

The results of this experiment failed to confirm our assumptions. We found no evidence that neural overlap between the processing regions of relevant and irrelevant stimulus information modified the processing of the irrelevant stimulus-part. However, it is clear from the reaction differences between both conditions that the motion task was harder compared to the colour task. Maybe this was caused by a high level of perceptual load involved in the present motion task (Lavie & Tsal, 1994). This may have exhausted the available processing capacity, which in turn may have decreased the extent to which the irrelevant distractor was processed (Rees, Frith, & Lavie, 1997). Further investigation is needed however, to evaluate this speculative assumption.

The fact that no SNARC effect was found whatsoever, not in the current experiment and not in the previous three experiments, raises questions about the actual possibility to process irrelevant numbers in a paradigm like this where motion has to be attended. We will return to this problem in the general discussion.

4.2 Searching for neural overlap effects in the ventral pathway

If the neural overlap mechanism is indeed a general cortical property that modulates and influences the way in which relevant and irrelevant infor-

mation is cognitively processed, then this mechanism should also be engaged elsewhere in the brain than in those regions along the dorsal processing pathway. With this idea kept in the back of our mind, we planned to use emotion expressed by faces in the next series of experiments. Faces expressing an emotion seem to be a promising candidate for the role of irrelevant stimuli because of the following reasons. First, emotions expressed by faces seem to interfere with responses to relevant tasks. Particularly, it has been shown earlier that the mere presentation of irrelevant fearful faces can interrupt the processing of the relevant stimulus part, resulting in slower responses compared to when happy or neutral faces are used (e.g. Hartikainen, Ogawa, & Knight, 2000; Vuilleumier, Armony, Driver, & Dolan, 2001; Burton et al., 2005). In the experiments presented here we will try to turn the interruption effect of fearful faces into our advantage. Secondly, it is well known that processing of faces mainly takes place in the fusiform face area, situated in the ventral pathway (see for instance Kanwisher, McDermott, & Chun, 1997). The emotion expressed by faces is an attribute primarily processed by the (right) amygdala, which receives projections from the ventral fusiform face area and V1. Furthermore, there are indications (Vuilleumier, Richardson, Armony, Driver, & Dolan, 2004) that the amygdala not only receives inputs from ventral visual cortical pathways, but also sends connections back to virtually all processing stages along the ventral visual system, including primary visual cortex (area V1) (Vuilleumier, 2005). This observation pronounces the strong ventral base (or neural overlap if you like) of face and emotion processing.

These properties of emotional face processing allow us to investigate neural overlap effects in the ventral processing pathway. We will present faces expressing emotions with tasks that are proportionally processed more or less within the ventral pathway. Indications pointing in the direction of neural overlap effects when processing irrelevant emotional faces were suggested

by two inspiring studies of Vuilleumier et al. (2001) and Pessoa, McKenna, Gutierrez, and Ungerleider (2002). In these studies the authors tried to find an answer to the question if emotional faces need to be attended in order to be processed. Earlier reports suggested that neural processing of emotional stimuli happens automatically, meaning that subjects can exhibit fast, involuntary autonomic responses to emotional stimuli (Globisch, Hamm, Esteves, & Öhman, 1999) and this may even take place without conscious awareness (Öhman, Esteves, & Soares, 1995).

The study by Vuilleumier et al. (2001) seemed to confirm this. In their displays they presented two pairs of houses and faces and the subjects had to make a same/different judgment on just one of the stimulus pairs. The behavioural results showed that responding to houses was interfered relatively more by fearful faces than neutral faces. More specifically, reaction times were slower with fearful irrelevant faces than with neutral ones, and this observation seemed to corroborate the assumption that faces are automatically processed even when they are irrelevant for the task at hand, and hence unattended. Pessoa et al. (2002) on the other side, disagreed with this assumption because they found no different effects of fearful and neutral faces. Of course, there were some differences between the task used by Pessoa et al. and the picture matching task from Vuilleumier and his colleagues. First of all, in the study by Pessoa et al. (2002) the faces were presented centrally on the screen, accompanied by two lateral oriented lines. In a first condition the subjects had to keep attention on the central face and judge if it belonged to a man or a woman. In the second condition on the other hand, subjects had to direct their attention towards the lateral lines and perform a same/different judgment on their orientation. The results contrasted those of Vuilleumier et al. (2001) in that no difference in reaction time was observed as a function of the emotional content of the unattended face during the line orientation task.

Pessoa et al. (2002) attributed the different outcome of their and Vuilleumier's study to the fact that their bar task exhausted processing capacity, leaving no resources for the irrelevant stimulus information (i.e., the face and its emotion) to be processed. This in contrast with the matching task used by Vuilleumier et al. (2001) which they believed was not as attention consuming as the bar orientation task, leaving enough bandwidth to process the irrelevant faces as well.

While the attention-based explanation for the erratic results is a viable one, it is clear that there are also differences between both tasks at the level of neural overlap. As indicated by the imaging data of both studies, orientation processing is relatively less related to emotional face processing, in comparison with processing pictures of houses. It could be the case that ignoring irrelevant faces is easier with a neurologically more distant task than with a relatively closer one. In the next couple of studies we will try to find an answer to this question by varying the neural relatedness of the main task with emotional face processing while keeping the irrelevant (face) material identical in all conditions. In line with the neural overlap account, we expect that emotional faces will interfere when doing a neurologically related task, as opposed to a smaller or absent effect when performing a neurologically less related task.

4.2.1 Experiment 5: gender versus colour

In a first experiment, the size of emotional face interruption will be compared between a gender classification and a colour discrimination task. Interruption effects of irrelevant fearful faces have been demonstrated earlier when performing a gender related task, which is not surprising because both gender discrimination and emotion processing depend on face processing. This gender task will be compared to a colour task. While colour processing also relies in large parts on ventral processes (Chao & Martin, 1999; Zeki, 1993;

Motter, 1994), it is functionally not related to face processing. In terms of neural overlap this means that processing the gender of a face is proportionally more related to facial emotion processing than colour processing. As a result, larger interruption effects are expected to occur when doing a gender task, compared to the colour task.

Method

Participants The number of participants was twenty-four and they all were students at the Victoria University of Wellington (New Zealand) participating for course credits. Eighteen were female and three of them were left handed. The average age of the participants was 23.25 ($SD = 7.27$). Each one of them had normal or corrected-to-normal vision and they all were naive with respect to the purpose of the experiment.

Stimuli Stimuli were frontal face pictures belonging to the Karolinska Directed Emotional Faces set (KDEF, see Lundqvist, Flykt, & Öhman, 1998). From this set, we selected 60 persons (30 men and 30 women) and from each person, pictures representing three emotions (fearful, happy and neutral) were added. This set of 180 pictures was subsequently doubled by making two versions of each picture: one version was blended with red and one with green. All pictures were manually edited so that only the face remained visible (no hair, shoulders, or background). The procedure for selecting practice stimuli from the KDEF-set was similar, but care was taken that none of the pictures was also selected for the experimental set. The faces were presented in the middle of the screen on a black background and they subtended an area of approximately 5.2 by 3.8 visual degrees.

Materials & Procedure All stimuli were presented on a 21-inch CRT-screen with a vertical refresh rate of 85 Hz and a resolution of 1024 by

768 pixels. The participants were seated so that the viewing distance was approximately 60 cm. The left and right responses were registered to the nearest millisecond using a response device produced by the technical staff from the psychology faculty at the Ghent University. The response box was placed at a comfortable position in front of the participant and she controlled the device by using the index fingers of both hands. The response buttons on the response box were situated 4 cm to the left and 4 cm to the right of the middle of the device. The experiment was programmed in Tscope (Stevens et al., in press) and controlled using a Pentium PC.

There were two conditions, a gender condition and a colour condition. In the gender condition, the task was to decide what the gender was belonging to the face-picture appearing on the screen. For the colour task, participants had to indicate the colour of the face they saw. Each participant ran through both conditions, but the order of the conditions was counterbalanced over participants.

Before each block, the participants received instructions for the current condition. Next and after the participant declared to understand the instructions, a practice block of 20 trials was initiated. During this practice block the participants received feedback about the correctness of their answer immediately after they had given a response. Once the practice block was finished, the experimental block was started up. In this experimental block, breaks were included after every sixtieth trial.

Each trial started with the presentation of a fixation point (a three-pixel wide white disc). After 1500 ms the fixation point was replaced by a face-stimulus. This target was removed from the screen after 200 ms and responses were registered until 1500 ms had passed by. Then a new trial began.

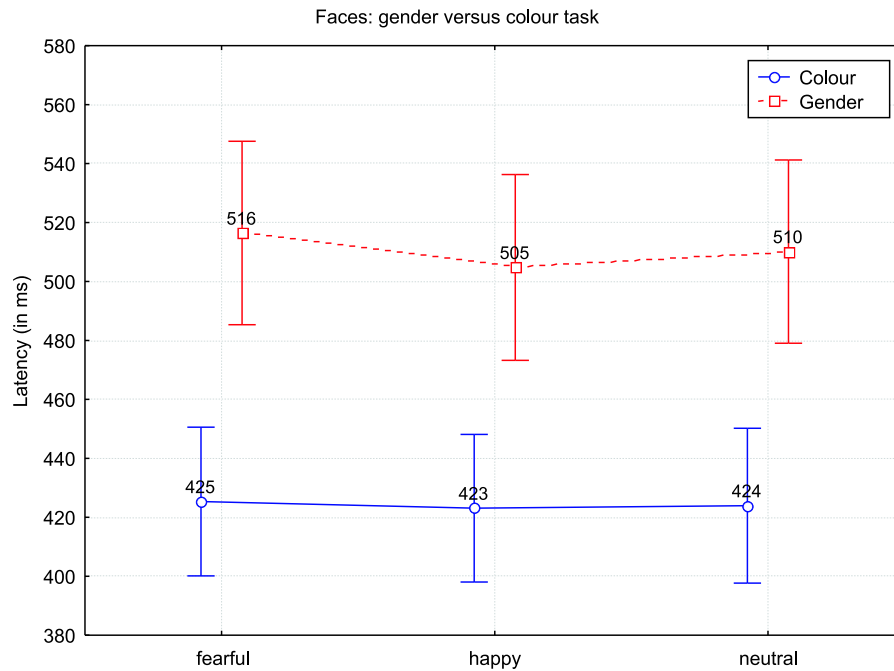


Figure 4.7: Experiment 1, average response times for each of the three emotional expressions used. The solid line depicts the colour condition, and the dashed line the gender condition.

Results

Less than one percent of the trials had to be removed because they were faster than 150 ms or slower than 1500 ms. On average, participants made 8.5% errors ($SD = 3$).

A 3×2 repeated measures ANOVA was run on the data using type of emotion (fearful, happy or neutral) and task (gender or colour) as within-subject variables. This resulted in a main effect of task and emotion (see Figure 4.7). Colour trials were faster than gender trials (424 versus 511 ms) with $F(1, 23) = 47.45$, $MSe = 5655$, $p < .001$. Moreover, RTs also varied as a function of the emotion expressed on the faces: average RTs for trials with fearful, happy and neutral faces were 471, 464 and 467 ms respectively

($F(2, 46) = 3.72$, $MSe = 157$, $p < .05$). Furthermore, the interaction between type of emotion and task was also significant ($F(2, 46) = 4.19$, $MSe = 64$, $p < .05$).

Post-hoc comparisons for the gender task showed that fearful faces were responded to slower than happy faces ($F(1, 23) = 9.33$, $MSe = 175$, $p < .01$). Fearful trials were also marginally slower than neutral trials ($F(1, 23) = 3.4$, $MSe = 140$, $p \approx .08$). No such differences between the types of emotion emerged for the colour task (all F 's < 1).

Finally, we also conducted a distribution analysis with vincentized bins for each quintile on both conditions (see Ratcliff, 1979; Van Zandt, 2000). Although no three-way interaction was present between the three within-subject variables task, emotion and bin, planned comparisons revealed some different patterns in the colour and the gender task (see Figure 4.8). Presenting fearful faces during the gender task resulted in significantly slower RTs than presenting happy faces, and this was true for all bins (Bin 1: $p \approx .07$; Bin 2: $p < .01$; Bin 3: $p < .001$; Bin 4: $p < .001$; Bin 5: $p < .05$; all one-tailed pairwise comparisons). On the opposite side, none of these pairwise comparisons were significant for the colour condition (all p 's $> .1$).

Discussion

It is clear that the emotional expression affected RTs in the gender task but not in the colour task. However, the different overall RT-levels cast serious doubts on the reliability of these differences. To further investigate this, an analysis of distributed RTs (bin analysis) was conducted. This showed that the origin of the emotion effects is not attributable to the differences in RT. For the gender task, effects of emotion are present throughout the whole RT range, while for the colour task these differences do not appear at any point in the distribution.

Together the results are more or less consistent with the hypothesis of

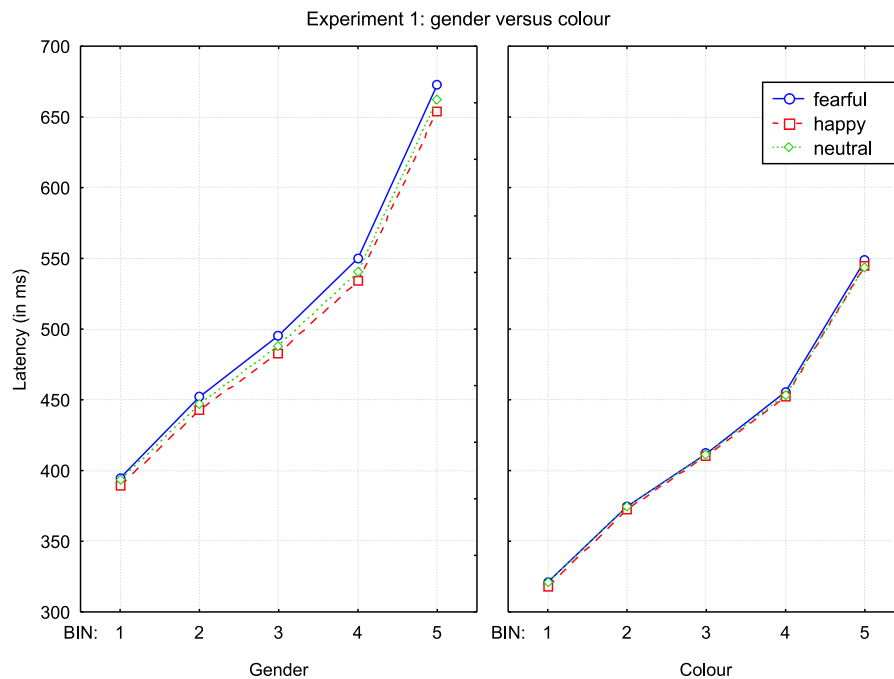


Figure 4.8: Experiment 1 distribution analysis showing vincentized RTs for each quintile

neural overlap: effects are present from the irrelevant emotion in the (neural and functional) closely related gender task, while this is not the case for the less related colour condition. However, even though the distribution analysis proved that the different effects between both tasks are not the result of the overall temporal processing difference, this still is a problem. Because slowing down performance in the colour task is no option (we already worked with highly similar colours) we conducted the next study.

4.2.2 Experiment 6: orientation versus colour

For this experiment we are reverting to the colour and orientation tasks used previously (see for instance Lammertyn et al., 2002). Because colour processing is neuro-anatomically closer related to face processing than orien-

tation processing (both colour and face processing largely ventral functions, while orientation processing is a predominantly dorsal function), the neural overlap hypothesis predicts larger interruptions of fearful faces in the colour condition compared to the orientation condition. These expectations are also supported by the assumption that inhibition of irrelevant information is believed to be more efficient when there is no neural overlap. When relevant and irrelevant information do overlap on the other hand, inhibiting the irrelevant information would counteract the relevant task which is processed along similar pathways. Therefore, inhibition of irrelevant information is anticipated to be less profound in the case of neural overlap.

Method

Participants Twenty-three psychology students from the Victoria University of Wellington (New Zealand) took part in this experiment in return for course credit. Five of them were male, and four were left-handed. Their average age was 20.43 years ($SD = 3.46$) and they all had normal or corrected-to-normal vision. No one was informed about the purpose of the experiment.

Stimuli The stimuli of the present experiment were in some aspects different from the previous experiment. This time, the stimulus display contained a central black and white picture of a face, accompanied by two vertically aligned grating stimuli, one at each side of the face. The grating stimuli were red or green discs (each with a diameter of 1 visual degree) filled with a grating that was oriented either close to the vertical or horizontal axis (see Figure 4.9 for some examples). The faces that we used were the same as in the previous experiment (180 pictures; 30 men and 30 women, each expressing two types of emotion and a neutral face).

Exactly the same face stimuli were shown in the orientation and the colour condition. In each condition, all faces were presented twice: once with the

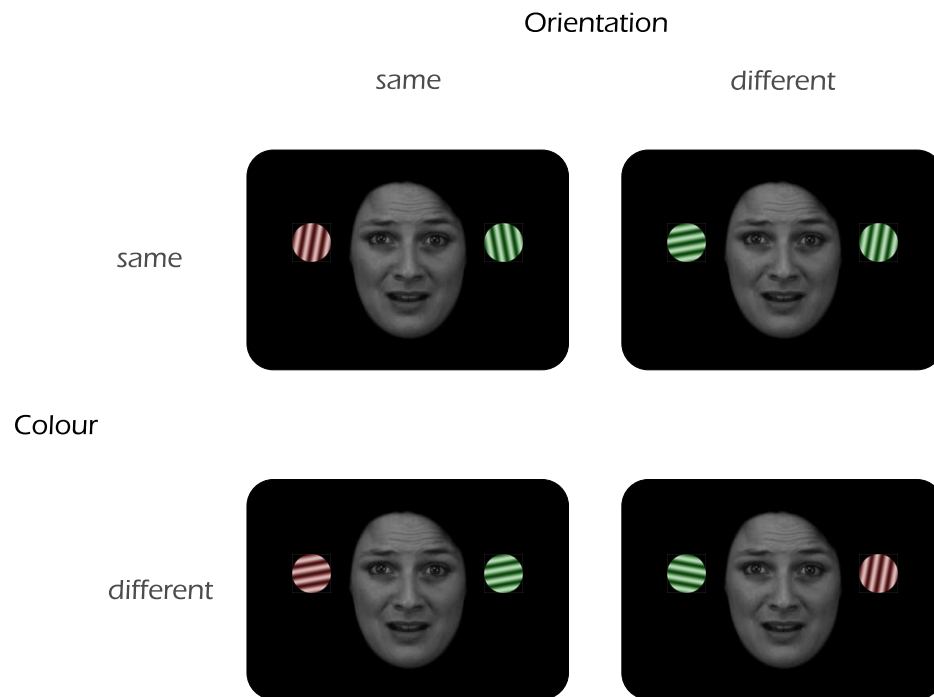


Figure 4.9: Examples of the displays used in Experiment 2. The colours represented in this picture are illustrative and may deviate from the exact colours used during the experiment.

same colour (or orientation) and once with a different colour (or orientation).

Procedure & Material The procedure and material used for this experiment were identical to the previous experiment, except for the fact that a different task was used. In the colour condition, the participants had to indicate with a left or right key press whether the discs had the same or a different colour. In the orientation condition participants had to judge if the orientations of the two gratings were both close to the vertical or horizontal axis, or if the orientations differed (one close to the vertical and another close to the horizontal axis).

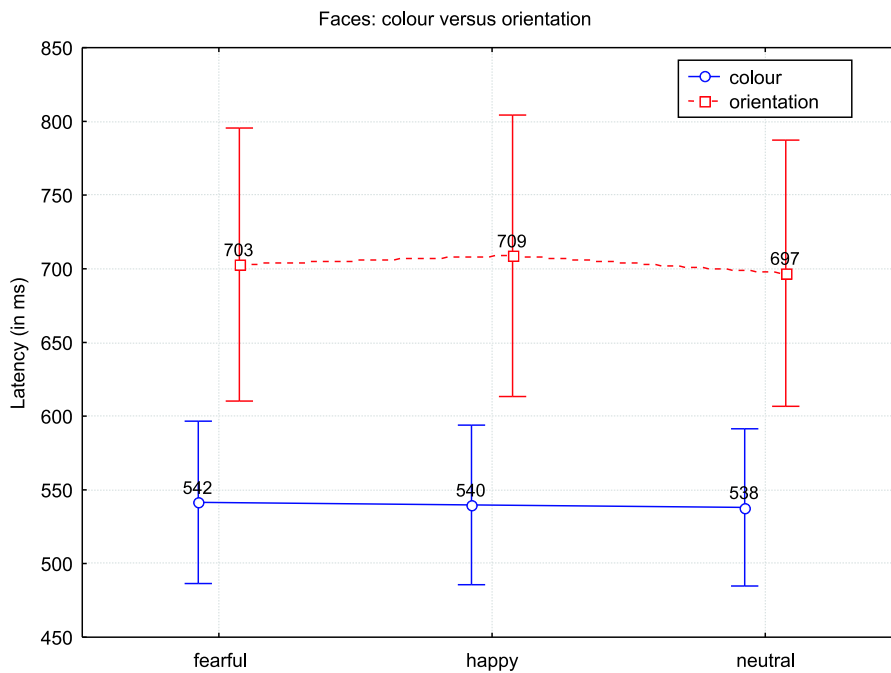


Figure 4.10: Experiment 2, average response times for each of the three emotions used. The solid line depicts the colour condition, and the dashed line the orientation condition.

Results

Before analyzing the data we removed trials with RTs faster than 150 ms and slower than 1500 ms (0.69%) and four participants with an overall error rate exceeding 10%. The average percentage of errors was 3.22% ($SD = 2.39$).

A $3 \times 2 \times 2$ repeated measures ANOVA with emotion, task and response congruence (whether the same/different judgments for both the orientation and the colour task in one trial were identical or not) as within-subject variables revealed nothing but an effect of task (see Figure 4.10). On average, colour trials were 163 ms slower than orientation trials ($F(1, 18) = 47.06$, $MSe = 32214$, $p < .001$). Response congruency had no effect on response speed (congruent trials 620 ms and incongruent trials 623 ms; $F < 1$), nor did emo-

tion (622, 624 and 618 ms for fearful, happy and neutral faces; $F < 1$). Furthermore, planned comparisons for the two conditions separately revealed no differences between trials with fearful, happy and neutral faces (all p 's $> .1$).

Discussion

The effects obtained in this experiment do not reveal anything to support the neural overlap hypothesis. The fact that there was a major task-effect, combined with the lack of emotion effects for each task separately makes us conclude that our manipulation has failed. However, based on these results it is impossible to make judgments about the neural overlap theory.

4.3 General Discussion

The purpose of this chapter was to investigate the general character of the neural overlap hypothesis. The evidence reported so far in earlier studies (Fias, Lauwereyns, & Lammertyn, 2001; Lammertyn et al., 2002; Lammertyn, Notebaert, Gevers, & Fias, manuscript submitted for publication) always employed the same type of stimuli, and hence similar processing regions were recruited for all of them. More specifically, because we consequently used orientation discrimination combined with either irrelevant number or spatial location processing as the critical condition for neural overlap, all the effects found in these studies rely heavily on processes situated along the dorsal pathway.

Two strategies were used in this chapter to investigate if the neural overlap hypothesis is indeed a general neuro-cognitive mechanism. A first part concentrated on the level of the feature. Up until now orientation was always the critical feature for the neural overlap condition. However, neural overlap effects should not be restricted to one specific feature and therefore an alternative feature was searched for orientation. Eventually motion was selected,

because just like number processing, motion also projects to dorsal processing regions more compared to colour (which was the relevant feature for the non-neural overlap condition). In a second part we looked for evidence that neural overlap effects are not specific for information processing along the dorsal pathway. To reach this aim we introduced an irrelevant interruption stimulus (faces expressing fear) that is supposed to be processed relatively more ventral. The question was now if the performance on a task would be affected more by the irrelevant interruption stimulus if the processing path of the relevant task also relies more on ventral systems compared to when this was not the case.

The outcome was surprising. First, none of the experiments using motion as the relevant feature did reveal any sign of neural overlap effects. There were no differences between the condition with neural overlap between relevant and irrelevant information, and the condition without neural overlap. For the second part, where irrelevant faces expressing emotions were used, the results were somewhat ambiguous. In one experiment, indications directing to neural overlap were found, but this was no longer true for the second experiment. Summed up, our strategy to find converging evidence for the neural overlap hypothesis did not work out. There were some minor indications, but overall nothing was found to support the generality of the neural overlap hypothesis. The question is now what possibly may have caused this failure to obtain neural overlap effects. Because most of the time no effects were found, formulating explanations for this inadequacy are ad hoc.

With regard to the motion experiments it is unclear why no neural overlap effects emerged. There is no reason to assume that motion is less suitable to obtain neural overlap effects compared to for instance orientation.

In the first face-experiment we did find indications of neural overlap effects when performing a gender task versus a colour task. This is not so surprising because it is obvious that a great deal of functional and neural

overlap exists between the gender task and the irrelevant emotion (both are carried by the same medium, i.e. the face). The implications for the neural overlap case should be minimized though because the RT levels were in no way equal between the two conditions. Regarding the second emotional face experiment, a possible reason for the failure to find a neural overlap effect might be related to the neuro-functional distances between the tasks used. The features and tasks employed in this experiment may have been just too far away from each other (both anatomical and functional) to overlap neurally. Matching the features and tasks employed in neural overlap experiments is a recurrent problem, since we completely rely on the literature at hand. We will elaborate further on this problem in the General Conclusions part of this dissertation.

For now, the implications for the neural overlap hypothesis are minimal. It is important to understand that although no evidence has been found supporting the neural overlap hypothesis, the outcome of the experiments did not directly oppose the neural overlap hypothesis neither. In the first part for instance, it was never found that the condition without neural overlap (i.e. the colour condition) had a statistically larger SNARC effect compared to the condition with neural overlap (i.e. the motion condition). By themselves each individual study showing a null-effect presented in this chapter may be harmless for the neural overlap theory. Yet, the repeated finding of such null-effects makes it difficult to deny that there is a problem. For this reason we may conclude that the question regarding the generality of the neural overlap hypothesis remains unanswered and that further in-depth investigation is necessary.

Chapter 5

Overview and conclusions

In general, this thesis contributed to the field of irrelevant information processing. More specifically, the scope of this thesis was to investigate the effect of relevant information processing on the quality of irrelevant information processing. To be able to account for our initial results, we introduced the “neural overlap” hypothesis. This hypothesis assumes that the translation from stimulus to response is not only influenced by the similarity of the mental codes associated with relevant and irrelevant information and responses (e.g. the dimensional overlap model; Kornblum et al., 1990), but also by the similarity of the neural regions that are involved in processing of the stimuli and responses. This similarity at the neural level was named “neural overlap” (in analogy of dimensional overlap), which is defined as the cortical and functional proximity of the processing regions of relevant and irrelevant information. Subsequently, the generality of this neural overlap hypothesis was scrutinized in a series of studies. Together, the ambiguous data gathered by these experiments question the feasibility of the neural overlap hypothesis.

5.1 Overview of the present experiments

The following paragraphs will give an overview of the studies presented in the present thesis.

The origin of the neural overlap hypothesis

The neural overlap hypothesis was proposed after we conducted a series of experiments to investigate the impact of irrelevant information on the processing of different types of relevant information. We compared a condition using colour discrimination as the main task, with a condition in which an orientation discrimination task was performed. The irrelevant stimulus consisted always of one-digit numbers, and the extent by which these were processed was investigated by looking at the size of the SNARC effect.

According to the dimensional overlap taxonomy of Kornblum et al. (1990), no differences could be expected between the different conditions because all trials in both conditions should be denominated as Type 3 ensembles (only irrelevant S-R consistency). Nevertheless, a larger SNARC effect was observed in the orientation discrimination condition compared to the colour condition meaning that the influence of the irrelevant information on the performance of the main task was different depending on the task that needed to be executed. To exclude alternative explanations we conducted a number of control experiments (see below).

First, we ruled out accounts in terms of relative speed differences. Because the RT level in our first pair of experiments was significantly lower for the colour condition than for the orientation condition, this may have induced the size difference in the SNARC effect. In an attempt to increase the RT level for the colour task, we repeated the colour experiment with colours that were harder to discriminate. As a result, the average RT for the colour condition was enhanced to the same level as the average orientation condition RT.

However, this manipulation did not alter our previous results: the SNARC effect in the colour condition was still smaller compared to the orientation condition.

Second, we ruled out stimulus-specific effects by replacing the oriented triangles by oriented lines, and in a later experiment, we also replaced the colour task by a shape identification task. Despite all these changes, the pattern of results remained the same: The SNARC effect was larger for the orientation task than for the colour and shape task.

Third, all comparisons in the previous experiments were made between conditions containing different kinds of stimuli. For instance, in our first set of experiments we compared a condition containing coloured numbers with a condition incorporating uncoloured numbers with an oriented triangle superimposed on it. To avoid possible visual confounds we conducted an experiment in which the stimuli were identical for both conditions while only the task varied. Again, we found that the condition in which an orientation task had to be performed resulted in a larger SNARC effect from the irrelevant numbers, compared to the colour condition.

Fourth, another possible confound in the colour versus orientation experiments was the fact that, strictly spoken, participants did not have to attend to the whole stimulus to be able to solve the task. Instead, they might have focused on a smaller part of the coloured number to derive its colour. Of course, this approach could have made it much easier to inhibit the irrelevant number information in the colour condition compared to the orientation condition in which the position of the whole number had to be attended to. To find out if this was the reason for the larger SNARC effect in the orientation condition, we developed a new colour task (see Experiment 7 of Chapter 2). Instead of filling up the inside of the numbers completely with one solid colour we now only filled up a part of the number with coloured dots. Additionally, the task of the participants was to decide which of two

colours was dominant. Because the coloured dots were randomly distributed over the whole number, it was impossible to derive the dominant colour by focusing on a small part of the stimulus. Nevertheless, the resulting RT pattern remained unchanged. The SNARC effect was still larger for the orientation task than for the colour task.

In sum, these series of control experiments are strongly in favour of the “neural overlap” hypothesis. No explanation except from neural overlap could account for the modulated processing of irrelevant information. The next step in our research was to broaden the scope the neural overlap mechanism, because up until now it was only studied within very specific circumstances.

Attempt to generalize the neural overlap hypothesis

The strategy in all the experiments conducted so far was to compare two conditions. With the exception of one experiment, we always compared a colour condition with an orientation condition. Furthermore, we always used numbers as irrelevant information and therefore the neural overlap condition always contained irrelevant numbers combined with a relevant orientation task, while the condition lacking neural overlap consisted of an irrelevant number combined with a colour or shape task. However, to be able to conclude that neural overlap is a general processing mechanism of the human brain, more evidence has to be gathered. Moreover, the strength of this converging evidence would be stronger if it would be obtained by using different paradigms and stimuli. Three strategies were followed to find additional evidence for the neural overlap hypothesis.

A first strategy was to use another type of irrelevant stimulus information. Whereas in the previous experiments the irrelevant numbers activated implicit spatial codes (i.e., the spatial mental location associated with numbers), we now chose to use explicit spatial locations. More specifically, we

employed the Simon effect instead of the SNARC effect. Again we compared colour with orientation tasks, and again we found the same pattern of effects as in the SNARC experiments. Conditions with neural overlap resulted in a larger Simon effect than conditions with a smaller degree of neural overlap.

A second strategy to find a more general basis for the neural overlap hypothesis was to replace the orientation feature by motion. We chose to use motion because in this way the experimental differences were only minimal. In terms of neural or dimensional overlap, the situation was not different from the SNARC experiments because motion was also considered to exert dorsal activations just like orientation. Unluckily this approach was unsuccessful, and we repeatedly failed to find a difference between the neural overlap condition and the condition without neural overlap.

A final attempt to obtain more evidence for the neural overlap hypothesis consisted of inducing neural overlap effects in the ventral pathway instead of the dorsal pathway. This was done by using stimuli consisting of facial emotions for which it is well-known that these are processed along the ventral pathway. However, a neural overlap effect observed in the ventral processing pathway using emotional face processing was only present in one experiment and even there its origin was ambiguous.

Why the generalization failed

It is clear that our efforts to generalize the neural overlap hypothesis failed. Especially the repeated observation of a null-effect found when using motion raises questions about the validity of a general neural overlap mechanism. But before drawing premature conclusions, we will consider post-hoc what possibly may have caused this disappointing results.

First, it could be the case that the effects of neural overlap obtained in Chapter 2 and 3 are specifically related to the use of an orientation task. Only in this task we unambiguously found a modulation of the SNARC or

Simon effect. However, simply assigning the effect to the use of a specific feature is not enough. One must also be able to tell why this specific task causes an effect while other tasks do not. One reason for this apparent task-specific modulation could have been completely unrelated to neural overlap, but rather to an indirect or non-evident association between orientation and numbers or between orientation and the response. However, re-analysis of our data revealed that the modulation found in orientation tasks does not originate from associations of this kind (see part II of Chapter 2 and the result sections of Chapter 3).

Second, another possibility is that neural overlap is a mechanism exclusively engaged in the dorsal pathway. At first glance, this seems unlikely because neural overlap is conceived as a mechanism that extremely depends on the spreading of activation within a highly interconnected cortical network, which is generally believed not to be restricted to specific parts of the brain. On top of that, although an exclusively dorsal focus of neural overlap effects might explain why there were no overlap effects ventrally, this possibility is not in concordance with the failure to obtain dorsal neural overlap effects while using motion.

Third, a more likely assumption is that neural overlap effects are much easier to observe within the dorsal pathway. The reason for this possibility is that dorsal (parietal) regions are considered as an interface between planned actions and the actual motor programs (e.g. Mattingley, Husain, Rorden, Kennard, & Driver, 1998; Rizzolatti, Fogassi, & Gallese, 1997). Because of the intimate relation between the dorsal processing pathway and the actual motor regions, effects of neural overlap rooted within the dorsal pathway may be reflected stronger in the reaction time pattern compared to neural overlap effects originating in the ventral processing pathway. Although this might be a valuable explanation, it is not in line with the repeated finding of a null-effect with the motion stimuli which were employed as an alternative to

orientation. This takes us to the question why the motion task did not elicit effects from the irrelevant information. Ad hoc, one could blame the absence of irrelevant information effects to the fact that motion stimuli are more difficult to discriminate. This possibly left insufficient attentional resources to process the irrelevant information (Lavie & Tsal, 1994; Rees et al., 1997). However, judging by the RT levels from the motion condition and the colour conditions this was probably not the case. In some of the motion experiments, the RT level was faster than for the colour task, which assumes that the motion task was easier. Of course, this argument only holds if our assumption that perceptual difficulty positively correlates with reaction time is correct.

Fourth, we might raise the question whether the correct control tasks were used. According to some studies, colour is also processed (partially) in the parietal cortex (Claeys et al., 2004). This issue needs more elaboration, especially because it is not clear if the effects obtained in this study could alternatively be attributed to attentional or response selection factors.

Fifth, a more general critique on all of the studies presented in this thesis concerns the fact that our selection of tasks was completely determined by what we know from literature. If this information is incorrect this may of course have had strong repercussions on our results. By using the data provided in literature, our experiments emphasized anatomical distance above functional distance. With regard to functional and also anatomical distance, we made a distinction between the dorsal and ventral processing pathway. Possibly, this differentiation may have been too sketchy to allow a clear discrimination of the neural overlap effects we were looking for. The ventral and dorsal processing stream may be anatomically different, but functionally they may not have been as independent as we have supposed.

5.2 Third party neural overlap research

The ambiguous results presented in this thesis raise doubts about the basic neural overlap idea. However, recent studies have shown that effects of neural overlap are not implausible. I will now discuss two studies that strongly refer to or depend on the idea of neural overlap.

Neural overlap predicts interference

The key question in the study by Pinel, Piazza, Le Bihan, and Dehaene (2004) was how comparative judgments are performed in the human brain (see also Cohen Kadosh et al., 2005; Fias et al., 2003). To do so, the authors scanned the participants by using fMRI while they were comparing stimuli for size, luminance or magnitude. The authors took care that performance was equated for each task and that identical stimuli consisting of Arabic digits varying in physical size, numerical size and luminance were used in all three blocks. The regions that are involved for comparing the different type of information were identified by criteria such as task-related activation, presence of a distance effect and interference of one dimension with another. What they found was a considerable amount of overlapping regions between the three comparison tasks, but importantly, the amount of overlap allowed to predict the amount of cross-dimensional interference and this both for the behaviour and imaging data. For instance, in the case of the distance effect they showed that the pattern of overlap matched the pattern of interference in response times. Neurally, number and size both recruited the anterior part of the horizontal segment of the intraparietal sulci (HIPS), while size and luminance overlapped in the posterior IPS and ventral occipito-temporal cortex. However, no posterior overlap regions were obtained between number and luminance. This was also reflected in the RT data. Interference was observed between number and size, size and luminance, but not between

luminance and number. Just like we have done before (see Chapter 2 and 3), Pinel et al. (2004) concluded that these results corroborate the hypothesis that the anatomical proximity between the neural structures activated by the relevant and irrelevant dimensions correlates with the amount of behavioural cross-dimensional interference.

Neural overlap between working memory and attention

In a review of the literature, Awh and Jonides (2001) concluded that there is a considerable amount of overlap between attention and working memory systems. More specifically, they gathered evidence which suggests that both spatial working memory and spatial attention processes rely on neural networks extending back from the frontal lobes into the primary sensory cortices (LaBar, Gitelman, Parrish, & Mesulam, 1999; Klingberg & Roland, 1997; Lucas & Lauwereyns, manuscript submitted for publication). This overlap is a possible explanation for the interference which occurs when delayed spatial working memory tasks and immediate spatial-attention tasks are performed concurrently (e.g. Awh, Jonides, & Reuter-Lorenz, 1998).

The idea of neural overlap causing specific interference between working memory and attention was further examined in studies by Lauwereyns, Wisniewski, Keown, and Govan (2005) and Lucas and Lauwereyns (manuscript submitted for publication). Inspired by Awh et al. (1998), these papers used a dual-task paradigm with an immediate feature-based attention task embedded within a delayed feature-based working memory task. More specifically, participants first had to memorize a feature of a stimulus (colour or shape). Next, and while keeping the feature of the first stimulus in memory, they had to select and compare a predefined feature (colour or shape) of two newly presented stimuli. Finally, the memorized colour or shape had to be compared with a subsequent presented stimulus.

In the Lauwereyns et al. study, it was shown that the relevant feature

in the working memory task primed the relevant features of the attention task. More specifically it was shown that the comparison task between the relevant features of the two stimuli presented during the attention task was easier when they belonged to the same dimension of the memorized relevant feature. Lucas and Lauwereyns (manuscript submitted for publication) took this one step further by investigating the potential effects of relevant features in working memory on *irrelevant* features in an attention task. Three displays were presented in each trial. The first display contained one stimulus of which the colour or shape had to be memorized. After some time, two new stimuli were presented for which the relevant colour (or shape) had to be matched, while the irrelevant shape (or colour) had to be ignored. After this was done, a final stimulus appeared and its colour or shape had to be matched with the memorized feature. The resulting data contained substantial congruency effects including faster responses in trials in which irrelevant on-line features pointed to the same response as the relevant on-line features, compared to when the irrelevant on-line features primed a different response than the relevant on-line features. This shows that the irrelevant features are difficult to ignore when they are simultaneously prioritized in working memory (Lucas & Lauwereyns, manuscript submitted for publication).

In their respective studies, Lauwereyns et al. (2005) and Lucas and Lauwereyns (manuscript submitted for publication) proposed that neural overlap between working memory and attention could best account for the results. Furthermore, they suggested that holding information in working memory implies attentional processing of that information, which actually means that attention functions as a subroutine of working memory.

Together the results of these specific studies show that by itself the neural overlap hypothesis is a valuable concept, although the results presented in this thesis have weakened the initial positive stance to some degree. Therefore, it is necessary and worthwhile to continue investigating the neural over-

lap hypothesis.

5.3 Contribution to the field of numerical cognition

Although the topic of this dissertation implied irrelevant information processing, part of it was picked up by the field of numerical cognition. A standing discussion in this field concerns the supposed automatic activation of number semantics. Consider for instance a task in which participants have to compare two numbers, for instance 2 and 3. At first sight, one would think that the comparison process is based on perceptual differences. The Arabic digit 2 and 3 are physically so different that there is no need to transform the symbols to their semantic meaning to be able to say that they are different. However, when the reaction time needed to compare 2 and 3 is opposed to the time needed to compare 2 and 7, it is invariably found that the latter comparison is faster. Because, 2 and 3 are semantically spoken more similar than 2 and 7 the former comparison process takes longer than one would expect on the basis of physical comparison alone. This “distance effect” (first described by Moyer & Landauer, 1967) is taken as an indication that numbers are indeed, automatically, converted into their semantic magnitude (Buckley & Gillman, 1974; Dehaene & Akhavein, 1995; Temple & Posner, 1998; Dehaene, 1992).

Another effect pointing to this “comprehension reflex” as Dehaene (1997) called it, is the size congruity effect. In 1982, Henik and Tzelgov let participants decide which of two Arabic digits was physically largest. They showed that, although numerical size did not matter for the task at hand, it apparently did influence the response time. More specifically, they found a congruency effect between numerical and physical size indicating automatic processing of number meaning. If the physical larger number was also the

numerically larger (e.g. 3 9), this resulted in faster responses compared to when physical and numerical size were incongruent (e.g. 3 9).

However, a problem with all these and other experiments proving the automatic character of magnitude coding is that they all involve numbers as relevant stimuli or tasks that require the semantic attributes of numbers. For instance, even for experiments showing semantic number-effects when using a parity task (which is considered to be *asemantic*), it cannot be denied that they are embedded within a numerical context. Therefore activation of number semantics is not necessarily automatic in the sense that it commences always and without restrictions. Rather, this may as well mean that the activation of number semantics is conditional and depends on the context in which the numbers are presented.

Our experiments using numbers as irrelevant information were different (see Chapter 2 and 3). Here, numbers were truly irrelevant. The information to which the responses had to be made was never numerical (colour, superimposed shapes, or orientation), nor were the tasks. Nevertheless we found semantic number effects (a SNARC effect) in some of the conditions. It was for this reason that the numerical cognition community picked up our experiments as the ultimate proof that numerical information is activated automatically and without contextual provocation (see for instance Gevers, Reynvoet, & Fias, 2003; Nuerk, Iversen, & Willmes, 2004; Reynvoet & Brysbaert, 2004; Turconi, Jemel, Rossion, & Seron, 2004; Gevers et al., 2005; Hubbard, Piazza, Pinel, & Dehaene, 2005; Ratinckx, Brysbaert, & Fias, 2005; Reynvoet, Gevers, & Caessens, 2005).

The question is now if this is really true. We clearly showed that there was only a SNARC effect under certain circumstances. More specifically, our neural overlap hypothesis stated that the size of the SNARC effect is related to the amount of neural overlap between the processing regions of the relevant task and the irrelevant numbers. This means that in the case of

neural overlap, activation of number semantics was modulated by another, simultaneous process and thus is not automatic but context driven. Apparently, Caessens et al. (2005) were the first to catch this nuance by stating that the mere existence of long-term shared dimensions across stimuli and responses is not a sufficient condition for congruency effects to arise. This remark referred to the fact that the colour experiments in Fias et al. (2001) and Lammertyn et al. (2002) did not result in a SNARC-effect, while the orientation experiments did.

5.4 Future directions

The biggest concern of this thesis is the fact that generalizing the neural overlap hypothesis to other parts in the brain failed. Especially the ambiguous results from the emotional face experiments were disappointing in this regard. However, the differences between emotional faces may have been too weak to be reflected in the behavioural data. A more apt approach to find different effects of irrelevant emotional faces while doing a colour or orientation task may have been to use neuro-imaging techniques. This way, it may have been possible to see if neural overlap between the colour task and irrelevant emotional faces results in larger amygdala activation, compared to an orientation condition which is cortically and functionally very well segregated from face processing. In line with Pessoa et al. (2002) and Vuilleumier et al. (2001), we would predict that neural overlap will cause larger emotion effect at the level of the amygdala when doing the colour task, compared to when conducting an orientation task. If this is confirmed, these results would definitely contribute to the usefulness of the neural overlap hypothesis as a common neural mechanism.

Another avenue to further investigate neural overlap is the paradigm used by Lauwereyns et al. (2005) and Lucas and Lauwereyns (manuscript submit-

ted for publication). They used a dual task procedure to examine the susceptibility of participants to irrelevant information in an immediate feature-based attention task as a function of the working memory condition (see also Jonides, Lacey, & Nee, 2005; Awh et al., 1999; Jonides & Awh, 2003, for a location based variant). In these experiments, the emphasis was on examining the effects of different visual dimensions on the congruency effect. However, this paradigm could as well be used to investigate the effect of neural overlap between attributes kept in working memory and an immediate attention task. Although a pilot study using this strategy seems hopeful, more work is necessary.

5.5 Conclusion

To summarize, the neural overlap hypothesis as it was originally presented initially proved to be a valuable concept. It allowed to explain data that was previously difficult to fit within dual route models like the dimensional overlap model. While intuitively neural overlap seems to be a simple mechanism, the failure to generalize it in this thesis shows that it may be more complex than originally thought. Therefore, this thesis should also be read as a manifest for further research on this topic. It is only by gathering a better knowledge of proximity and functional connectivity of specialized brain regions that our understanding of the precise mechanisms underlying neural overlap will improve.

Chapter 6

Samenvatting

In ons dagelijks leven worden wij constant geconfronteerd met een enorme stroom van informatie. Continu worden onze zintuigen geprikkeld door stimuli die niet altijd even belangrijk zijn voor ons. Het mag dan ook verbazing wekken dat wij desalniettemin in staat zijn om ons op een georganiseerde manier voort te bewegen in deze informatiestroom. Wat stelt ons nu in staat om om te gaan met al deze informatie? Om niet ten onder te gaan aan de enorme hoeveelheid informatie die onze hersenen bereikt, beschikken deze over een aantal mechanismen om doelgericht belangrijke informatie te selecteren. Zo zijn wij bijvoorbeeld in staat om onze aandacht heel gericht te focussen op een klein deel van ons gezichtsveld. Op een gelijkaardige manier kunnen wij ook onze gevoeligheid voor relevante kenmerken verhogen (facilitatie) en de gevoeligheid voor irrelevante kenmerken onderdrukken (inhibitie) om zo gemakkelijker de aandacht op relevante stimuli te kunnen vestigen.

Alhoewel ons informatieverwerkingssysteem dus kan beschikken over de nodige mechanismen om relevante en irrelevante informatie uit elkaar te houden werkt dit niet altijd feilloos. Het is mogelijk dat informatie die niet relevant is voor de taak die je aan het uitvoeren bent toch binnensluipt in het systeem. Vaak gaat dit gepaard met interferentie op de eigenlijk uit te voeren taak. Zo kan het bijvoorbeeld zijn dat je trager tot de juiste respons komt, of

slechter nog, dat je fout reageert. Een mogelijke vraag is waarom irrelevante informatie überhaupt wordt verwerkt. Er zijn vele mogelijke verklaringen, maar het doel van deze thesis was te onderzoeken of “neurale afstand” in dit opzicht een rol zou kunnen spelen. Met neurale afstand bedoelen we de afstand tussen de verwerkingsgebieden die instaan voor de verwerking van de relevante informatie en deze die instaan voor de verwerking van irrelevante informatie. Het is belangrijk in te zien dat afstand in onze hersenen relatief is. Zo kan het zijn dat gebieden die in absolute termen ver van elkaar af liggen toch dichtbij zijn omdat de connecties ertussen heel sterk zijn. Anderzijds is het ook mogelijk dat gebieden aan elkaar grenzen (bijvoorbeeld de twee zijden van een sulcus), maar in termen van connecties heel ver van elkaar zijn verwijderd.

Hoe kan neurale afstand nu een rol spelen bij het al dan niet efficiënt inhiberen van irrelevante informatie? Om dit te kunnen vatten is het belangrijk de organisatie en werking van onze hersenen beter te begrijpen. In ons brein kunnen verschillende regio’s worden onderscheiden die instaan voor de verwerking van allerlei soorten informatie. Nu is het niet zo dat deze gebieden daadwerkelijk zijn afgegrensd van elkaar. Wel integendeel: de kracht van ons brein schuilt voornamelijk in de verregaande complexiteit van de aanwezige connecties tussen zenuwcellen enerzijds en de onderscheiden verwerkingsgebieden anderzijds. Wanneer een bepaald type informatie wordt verwerkt, gaat dit gepaard met de activering van de neuronen in het desbetreffende verwerkingsgebied. Een belangrijke eigenschap van deze neuronale cel-activiteit is dat deze niet beperkt blijft tot de verantwoordelijke zenuwcel, maar uitdijt naar dichtbijgelegen zenuwcellen. Men noemt dit fenomeen “spreading activation” of de zich verspreidende activering. Het is nu onze veronderstelling dat deze verspreidende activatie ervoor kan zorgen dan neurale afstand bepaalt of irrelevante informatie wordt verwerkt of niet. Probeer je bijvoorbeeld de situatie in te beelden waarbij het verwerkingsgebied voor

de relevante informatie zeer dichtbij het verwerkingsgebied van de irrelevante informatie ligt. Om beter de relevante informatie te kunnen verwerken zal ons aandachtssysteem normaal gezien trachten de signaal-ruis verhouding van de relevante verwerkingscellen te verbeteren, om zo te komen tot hogere activatieniveaus. Echter, indien de relevante verwerkingsgebieden dicht bij de irrelevante verwerkingsgebieden liggen, zal een verhoogd activatieniveau leiden tot een sterkere aanvoer van zich verspreidende activatie. Dit kan er op zijn beurt voor zorgen dat de inhibitie van irrelevante informatieverwerking moeilijker zal zijn. Het resultaat hiervan is dat de irrelevante informatie alsnog wordt verwerkt en een invloed kan hebben op de relevante stimulus-respons vertaling. De vaststelling dat de mate van interferentie veroorzaakt door irrelevante informatie afhankelijk is van de afstand tussen relevante en irrelevante verwerkingsgebieden vatten wij samen in de neurale overlap hypothese.

6.1 Aanzet tot de neurale overlap hypothese

In het tweede hoofdstuk van deze thesis komen studies aan bod die de aanzet vormden voor de neurale overlap hypothese. Deze hypothese is een uitbreiding van het *dimensional overlap model* van Kornblum et al. (1990) wat stelt dat de mate van interferentie die ontstaat tussen de verschillende stimulus-kenmerken en de respons, afhankelijk is van de onderlinge relaties tussen de betrokken dimensies. Deze dimensies worden gedefinieerd aan de hand van enkele parameters. Zo kunnen zij ofwel betrekking hebben op de stimulus ofwel op de respons. Bovendien kunnen de dimensies al dan niet relevant zijn voor de huidige taak. Een voorbeeld van een dimensie aan de stimuluszijde is kleur. Twee concurrerende stimuli kunnen dezelfde kleur hebben, en in dat geval is er sprake van overlap binnen de kleurdimensie. Ook aan de responszijde kan er dimensionele overlap zijn (beide processen leiden bijvoor-

beeld tot een respons “rechts”) en zelfs tussen stimulus- en responsniveaus is dimensionele overlap mogelijk (de stimulus is bijvoorbeeld een pijl naar links en de respons is een druk op een knop die zich links bevindt).

De neurale overlap theorie gaat hierop verder en stelt dat niet enkel een overlap op dimensionaal vlak een rol kan spelen bij het creëren van interferentie-effecten, maar dat ook de mate van neurale overlap belangrijk is. Met neurale overlap wordt bedoeld dat de onderliggende neurologische structuren die nodig zijn voor de verwerking van verschillende stimuli functioneel en/of anatomisch verwant zijn. Concreet werd er in het eerste deel van Hoofdstuk 2 aangetoond dat er situaties mogelijk zijn waarbij er geen dimensionele overlap is tussen de relevante en irrelevante stimuli, maar waar er toch interferentie ontstaat wanneer beide tegelijkertijd worden aangeboden. De bepalende factor was in dit geval steeds de mate van neurale overlap. De keuze voor de stimuli die werden gebruikt in deze studies was vooral gebaseerd op de gebieden waarin ze worden verwerkt. Zo werden als irrelevante stimuli steeds getallen gebruikt omdat uit de literatuur bekend is dat getallen spatiale connotaties hebben en deze in de dorsale verwerkingsstroom verwerkt worden. De irrelevante stimuli werden zo gekozen dat zij ofwel ook dorsaal werden verwerkt (bijvoorbeeld “oriëntatie”), ofwel helemaal niet dorsaal, maar ventraal werden verwerkt (bijvoorbeeld vormherkenning). Op deze manier werd er een conditie gecreëerd waarbij er neurale overlap is maar geen dimensionele overlap (beoordelen hoe irrelevante getallen georiënteerd zijn) en een conditie waarbij er noch neurale, noch dimensionele overlap aanwezig is (de kleur bepalen van een irrelevant getal). De resultaten toonden aan dat de getallen in de neurale overlap-conditie tot op semantisch niveau worden verwerkt, terwijl dit niet zo was voor de conditie zonder neurale overlap. Deze resultaten kunnen niet worden verklaard aan de hand van het dimensional overlap model aangezien er in beide condities op geen enkel niveau dimensionele overlap aanwezig was. Vandaar dat wij tot de conclusie kwamen dat

de enige verklaring voor dit verschil gezocht moest worden in de mate van overlap van de onderliggende neurale structuren die gebruikt worden voor de verwerking van de irrelevante getallen en de relevante taak.

In het tweede deel van Hoofdstuk 2 werd nagegaan of alternatieve mechanismen aan de basis zouden kunnen hebben gelegen van de eerder gevonden effecten. Zo werd bijvoorbeeld onderzocht of de verschillende manieren waarop aandacht kan worden besteed aan kleur dan wel oriëntatie een rol zou kunnen hebben gespeeld. Meer specifiek zou het bij kleurbeoordeling mogelijk zijn geweest dat de proefpersonen focusten op een heel klein deel van het irrelevante getal, om zo het getal zelf gemakkelijker te kunnen negeren en uit te sluiten van verdere verwerking. Om deze verklaring uit te sluiten boden we in een volgend experiment getallen aan die waren opgevuld met gekleurde pixels. De taak van de proefpersonen bestond er in te reageren op de vaakst voorkomende kleur. Omdat de spreiding van de pixels was gerandomiseerd over het gehele oppervlak van het irrelevante getal, was het nu onmogelijk om doelgericht te focussen op een heel klein deel van de stimulus. De resultaten van dit onderzoek waren in het voordeel van de neurale overlap theorie: nog steeds werden de irrelevante getallen het sterkst verwerkt in de conditie met neurale overlap.

Naast het gebruik van irrelevante getallen, onderzochten we in Hoofdstuk 3 of neurale overlap-effecten kunnen optreden met een ander soort van spatiale informatie. Meer specifiek gebruikten we locatie. Eind de jaren zestig toonde Simon aan dat stimuli die aan de rechterkant worden aangeboden ook sneller worden beantwoord met een rechter response (of vice versa met links), en dit zelfs indien de locatie van de stimulus zelf niet relevant is voor het uitvoeren van de taak (bijvoorbeeld omdat je op de kleur van de stimulus moet antwoorden) (Simon & Rudell, 1967). Dit effect werd het Simon-effect genoemd en kan perfect worden verklaard binnen de taxonomie van Kornblum (Kornblum et al., 1990). Wanneer een stimulus ons sensorisch

systeem betreedt worden zowel de relevante als irrelevante kenmerken ervan gecodeerd. Dit leidt bijvoorbeeld tot de activering van de codes “rechts” en “groen” (in het geval van een groene stimulus die rechts staat) ook al is de locatie zelf irrelevant. Indien een groene stimulus vereist dat er een rechter respons wordt gegeven zal dit gemakkelijk verlopen aangezien de code “rechts” reeds werd geactiveerd door de irrelevante stimuluspositie. Had de stimulus links gestaan, dan zou deze dimensionele overlap er niet zijn geweest en zou er geen versnelde activering van de respons mogelijk zijn geweest. Dit verschil vertaalt zich in het Simon-effect.

In onze studie wilden we te weten komen of de grootte van het Simon-effect (of anders, de mate waarin irrelevante positie-informatie wordt verwerkt) afhangt van de graad van neurale proximateit tussen de gebieden die verantwoordelijk zijn voor de verwerking van de relevante taak en de irrelevante positie-informatie. We deden dit door verschillende taken te gebruiken die in mindere of meerdere mate verwant zijn met positie-verwerking. Vervolgens werd gekeken of deze gradaties in neurale overlap een effect hadden op het Simon-effect. Net zoals in het tweede hoofdstuk waren de resultaten in overeenstemming met de neurale overlap hypothese. Wanneer de relevante en irrelevante stimulus-informatie nauwer verwant waren vergrootte het Simon-effect in vergelijking met wanneer de twee stimulus-attributen neuraal niet overlaptten.

6.2 Generalisatie van de neurale overlap hypothese

Tot nu toe maakten we voor de neurale overlap conditie steeds gebruik van oriëntatie als relevante informatie en getallen of locatie als irrelevante informatie. Indien we de neurale overlap hypothese willen veralgemenen is er echter meer convergerende evidentie nodig. Om deze doelstelling te bereiken,

volgden we twee onderzoekslijnen. Een eerste strategie bestond er in neurale overlap effecten aan te tonen met een andere relevante taak dan oriëntatie. Deze stap was belangrijk om aan te tonen dat de eerder gevonden effecten niet louter taak- of stimulus-specifiek zijn maar kunnen veralgemeend worden, onafhankelijk van de taak of stimuli die worden gebruikt. Concreet gebruikten we in plaats van oriëntatie, bewegingsdetectie als nieuwe “dorsale” taak. Net als oriëntatie kan de verwerking van beweging worden gesitueerd in de dorsale verwerkingsstroom (Galletti & Fattori, 2003; Orban et al., 2003). De resultaten waren echter teleurstellend. We vonden geen neurale overlap effecten en dus was het onmogelijk om op basis van deze resultaten te komen tot de vooropgestelde veralgemening van het neurale overlap principe.

Een tweede onderzoeksmethode die werd gevolgd om te komen tot de veralgemening van de neurale overlap theorie, bestond er in dit effect aan te tonen binnen een ander gebied van de hersenen. In vorige studies was het altijd zo dat de stimuli die werden gebruikt overlap vertoonden in eenzelfde belangrijke verwerkingsstroom van onze hersenen, namelijk de dorsale stroom. De zogenaamde “tegenhanger” van deze dorsale stroom is de ventrale stroom, die naast de functionele verschillen ook volledig verschilt op het gebied van de aangewende neuro-anatomische structuren. Concreet was het de bedoeling neurale overlap effecten aan te tonen binnen de ventrale verwerkingsstroom. Om deze doelstelling te bereiken maakten we gebruik van emotionele gezichtsstimuli waarvan is geweten dat zij ventraal worden verwerkt. Belangrijk voor het huidige onderzoek is de waarneming dat stimuli die negatieve emoties uitdrukken tot een vertraagde reactie (kunnen) leiden in vergelijking met neutrale of positieve stimuli. We gingen uit van een studie van Pessoa et al. (2002) en een studie van Vuilleumier et al. (2001). Beiden onderzochten in welke mate aandacht nodig is om de emotie die gezichten uitdrukken te verwerken en beide kwamen tot een verschillende conclusie. Waar Vuilleumier et al. (2001) vonden dat emotionele uitdrukkingen op gezichten

automatisch worden verwerkt onafhankelijk van aandacht, kwamen Pessoa et al. (2002) tot de conclusie dat er wel degelijk aandacht moet worden geschonken aan een gezicht zodat de valentie ervan zou worden verwerkt. Het is wel belangrijk te weten dat Vuilleumier et al. (2001) een identificatietaak gebruikten (matching van huizen, met irrelevante gezichten), terwijl Pessoa et al. (2002) gebruik maakten van een oriëntatietaak (matching van lijnoriëntaties met irrelevante gezichten). Als je dit binnen het kader van de neurale overlap theorie beschouwt, lijken de verschillende uitkomsten verklaard te kunnen worden aan de hand van de verschillen tussen de betrokken neurale structuren in beide taken. De taak van Vuilleumier et al. (2001) sluit nauwer aan bij gezichtsverwerking dan de oriëntatietaak van Pessoa et al. (2002). Een eventueel gevolg daarvan is dat emoties gemakkelijker en zelfs automatisch worden verwerkt in de taak van Vuilleumier et al. (2001) in tegenstelling tot die van Pessoa et al. (2002). In deze studie wilden we controleren of deze neurale overlap verklaring inderdaad klopt door beide taken rechtstreeks tegenover elkaar te stellen.

De resultaten waren ambigu. Waar er in een eerste experiment wel degelijk effecten werden gevonden die konden doorgaan voor neurale overlap effecten was dit niet meer het geval in een tweede studie. Bovendien waren er in het eerste experiment problemen met het gelijk houden van de reactietijd-niveaus tussen de verschillende condities. Deze temporele verschillen tussen de twee condities zouden op zich al een verklaring kunnen zijn voor de verschillende mate van irrelevante informatieverwerking, los van neurale overlap. We kunnen dus samenvatten dat deze experimenten niet toelaten te stellen dat neurale overlap ook werkzaam is binnen de ventrale verwerkingsstroom.

6.3 Redenen van mislukken

Het is duidelijk dat onze poging om de neurale overlap theorie te generaliseren is mislukt. De vraag is nu wat er mogelijk aan de oorsprong zou kunnen liggen van deze ontgoochelende resultaten. In Hoofdstuk 5 werd getracht een antwoord te vinden op deze vraag. Alhoewel een eenduidig antwoord niet kon worden gegeven is er toch de belangrijke bedenking dat voor de lokalisatie van de gebruikte taken en stimuli steeds een beroep moest worden gedaan op wat er in de literatuur voorhanden is. Indien deze informatie onjuist is kan dit nefaste gevolgen hebben gehad voor de resultaten van ons onderzoek. Door gebruik te maken van locatie-gegevens uit de literatuur, lag de nadruk van de gebruikte relevante en irrelevante kenmerken voornamelijk op anatomische afstand. In onze experimenten maakten wij vooral gebruik van goed bestudeerde opdeling tussen ventrale en dorsale verwerkingsbanen binnen onze hersenen. Het is nu mogelijk dat deze dissociatie te vaag was om duidelijke verschillen in neurale overlap te kunnen bewerkstelligen. De dorsale en ventrale verwerkingsbanen kunnen dan misschien anatomisch verschillen, door de vele interconnecties is het functionele onderscheid dan misschien toch niet zo groot als we steeds veronderstelden.

6.4 Conclusie

Uit initieel onderzoek bleek dat de neurale overlap hypothese een valabel concept is. We slaagden er echter niet in om de de neurale overlap hypothese te generaliseren. Het gebruik van andere stimuli en taken die al dan niet binnen dezelfde regionen worden verwerkt als de eerste experimenten, leverde geen data op die de neurale overlap hypothese ondersteunen. Aangezien het nog steeds onduidelijk is waarom onze poging tot generalisatie mislukte, en fMRI-data verzameld door derden (Pinel et al., 2004) wel degelijk in de richting wijzen van neurale overlap mechanismen, zouden wij ervoor willen

pleiten verder onderzoek te voeren naar dit, op het eerste zicht, eenvoudige principe.

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